JOURNAL OF BAKU ENGINEERING UNIVERSITY-ADVANCES IN CHEMISTRY AND CHEMICAL ENGINEERING
**2024. Volume 8, Number 2** **Pages 99-108**

**UOT:665.63-404;665.637.64**
**DOI:** https://doi.org/10.30546/2521-6317.2024.2.210

# SIMULATION STUDY ON ENHANCED OIL RECOVERY USING LOW-SALINITY WATER TREATED WITH A MAGNETIC FIELD

**Elnur ALIZADE***

[1] *Department of Petroleum Engineering,*
*Azerbaijan State Oil and Industry University,*
*Azadliq Avenue, 20, AZ1010, Baku, Azerbaijan*

**ARTICLE INFO**

*Article history*
Received: 2025-01-10
Received in revised form:2025-04-11
Accepted: 2025-04-11
Available online

*Keywords:*
*Magnetic field;*
*modelling;*
*waterflooding;*
*salinity;*
*wettability;*
*rock.*

**ABSTRACT**

*The waterflooding technique is one of the most widely used and efficient technique for increasing oil recovery. In an oil-wet reservoir, however, the higher the water mobility, the lower the oil production. The following research will look into the effects of high and low saline waterfloods on oil recovery and water mobility with application of magnetic field. This research also looks at how varied water salinity injections affect wettability and salt production rates. The design of a three-dimensional, two-phase model, i.e., water and oil, is the first step in this research. Initially, the reservoir is oil-wet. To show the wettability change, relative permeability curves are generated during simulation. The impact of salinity on oil production, water mobility, and salt production is examined by a comparison of high and low saline waterfloods. In order to identify an effective well injection technique, a sensitivity analysis was done for two possible injections well patterns: five spot and direct line drive. The recovery attained by lowering the salinity of the water was found to be around 80%, with a cumulative oil production of 0.45 MMSTB. The water cut is prolonged to a large extent by lowering the salinity of the water.*

## 1. Introduction

Based on formation characteristics, fluid characteristics, reservoir heterogeneities, and PVT characteristics of the reservoir, oil recovery during the life of a reservoir is split into three stages (Ahmed 2006) [1]. According to Abubaker H. Alagorni (2015), the main recovery is based on the natural energy of the reservoir and has a recovery factor that is less than 30% of OIIP. Primary recovery also includes artificial lift techniques. The recovery from the secondary mechanism is between 30 and 50 percent of OIIP [2]. Waterflooding was first utilized as a pressure maintenance source for oil recovery in 1880, but it is now universally acknowledged as one of the most popular fluid injection techniques, mainly from the United States, between 1930 and 1950 (Cobb 1997) [3].

The low salinity waterflooding (LSF) EOR technology improves oil recovery by reducing the salinity of the injection water. In the last ten years, low saline waterflooding (LSW) has emerged as a new and promising enhanced oil recovery strategy for carbonate and sandstone reservoirs

* Corresponding author.
*E-mail addresses*: **e.alizade.99@gmail.com (Elnur Alizade).**

[4]. The low saline waterflooding has gained a lot of interest from the oil sector due to its simplicity and inexpensive cost. When Bernard and his colleagues tested the oil recovery using (NaCl) sodium chloride brine injection varying from 0-1 percent with distilled water injection. Additionally, their research has indicated that the injection of sodium chloride brine, ranging from 1 to 15%, has no impact on oil recovery (Bernard 1967) [5].

Recently, the application of magnetic fields has been investigated as an innovative approach to enhancing the efficiency of waterflooding. Magnetically treated water exhibits altered physicochemical properties that influence interactions with reservoir rock and fluids. Studies suggest that exposure to a magnetic field can modify ion interactions, enhance the dissolution of salts, and influence fines migration, all of which contribute to improved oil recovery. Furthermore, the magnetic field may facilitate wettability alteration and reduce interfacial tension, enhancing the displacement of oil in the porous media. This integration of magnetic fields with low-salinity waterflooding represents a novel enhancement to traditional EOR strategies, offering additional recovery potential with minimal cost and complexity.

In the laboratory core flood test and at the field scale, it is demonstrated that Low Salinity waterflooding improves oil recovery The suggested mechanisms for low-salinity waterfloods are listed below [6,7]:

- Increased pH
- Fines migration
- Multicomponent Ionic Exchange (MIE)
- Double Layer Expansion (DLE)
- Wettability Alteration

Thus, integrating magnetic field technology with low-salinity waterflooding has the potential to revolutionize oil recovery processes by further enhancing recovery efficiency while maintaining operational simplicity and cost-effectiveness.

## 2. PROBLEM STATEMENT

In this study, water is injected through an injector using both low- and high-saline water injection procedures, and oil is recovered from the production well. The following undesired issues were discovered in this simulation study:

- Earlier water breakthrough
- High salt production rate
- Unaltered oil-wet reservoir conditions

Predictive modelling can be used to identify and fix the existing challenges.

## 3. OBJECTIVES OF STUDY

The objectives of this study are:

- To choose an optimum injection design (such as direct line drive and five spot pattern) for an effective displacement of the oil.
- To study the effect of low and high saline water injection in oil wet sandstone reservoir.

The objective of this study is to evaluate the performance of a sandstone reservoir following the injection of low and high salinity water. The reader is intended to develop a clearer understanding of the mechanisms by which low saline water removes oil from reservoirs and changes the wettability of formations from oil-wet to water-wet, improving oil recovery. For the purpose of choosing an optimized injection method to achieve maximum oil recovery, a sensitivity analysis for various injection well patterns are also performed.

The performance of an oil-wet sandstone reservoir under low and high salinity waterflooding is determined in this experiment. A flowchart in Figure 1 shows a brief overview of the steps that have been followed in this work.

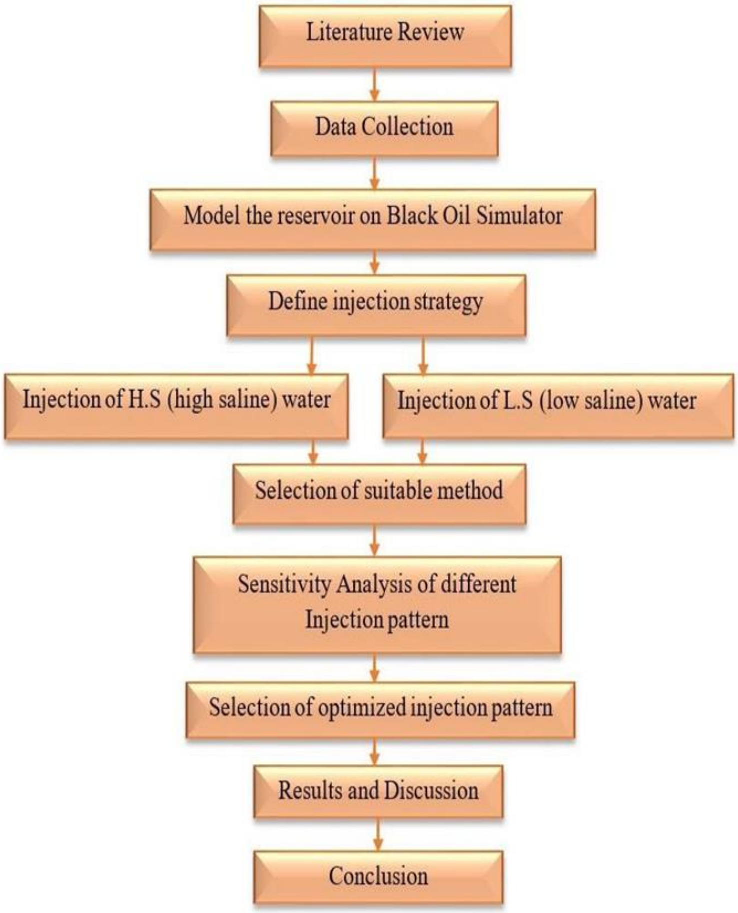


**Fig. 1** A systematic workflow diagram for analysis of salinity effects in waterflooding technique.

The reservoir data was first obtained via a literature review, and after that, a simulation model was created using a black oil simulator, such as Eclipse-100 (a commercially available simulation software). In order to determine the best injection technique, simulations for continuous low- and high-saline water injection were run. Later, a sensitivity analysis was performed using simulated data for the five-spot pattern and direct line drive well injection techniques. After that, based on technical factors including water cut, oil output, and salt production, the best injection well plan was chosen in the conclusion section.

## 4. CASE STUDY

A part of Shaybah oil field is under consideration in this study which is located in Rub'al Khali desert in Saudi Arabia. A well was spud in this field and is now under a need to waterflood, this study gives a brief consideration whether high saline or low saline water will be most efficient in order to produce oil from this field in commercial quantity. Reservoir specifications are taken and a simulation model was generated by considering that this model replicate the original reservoir conditions and methods that are tested in the simulation will be best applicable on the actual reservoir. The description of reservoir simulation model is as follow:

*Description of reservoir model:*

In this study, a 3D reservoir model with a square geometry of 334 acres area is simulated on a black oil simulator. The reservoir model has dimensions of 492 ft, 492 ft, and 30 ft in I, J, and K directions, respectively. The developed model is heterogeneous so, it compromises 50, 50 grid blocks in the I and J direction respectively but has 6 layers in the K direction. At the Initial stage, there are two active phases present in the reservoir i.e., oil and water. The reservoir has a permeability of 275-525 md and porosity of 23-31% (Fig. 2).

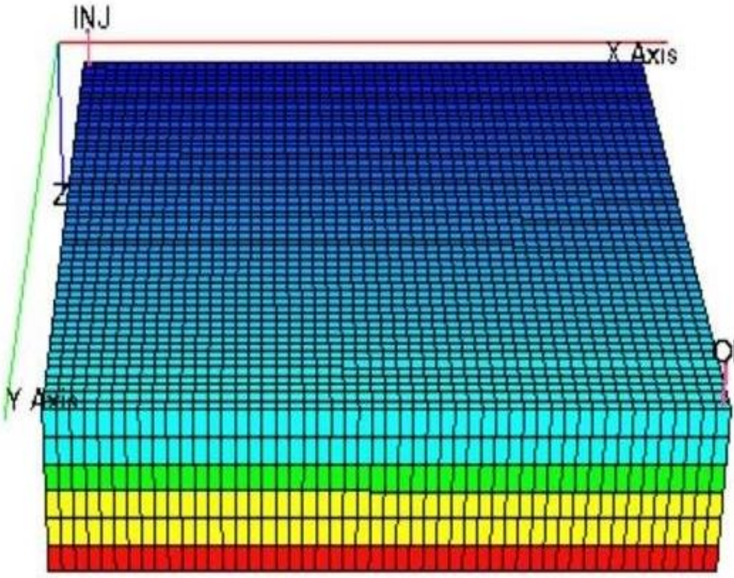


**Fig. 2** A 3D reservoir model representing Injector (INJ) and Producer (OP) wells.

An injection well and a production well are located on the opposite corners of the model. Injection well is represented by INJ and production well is represented by OP. The simulation is carried out for a period of 5 years.

*Developing a Reservoir Model*

In this study, the simulation for the base case is carried out in the following steps:

*Model Dimension*

In Eclipse 100, the first step for developing a model is to define the title of the run, geometry to be used, number of cells in each direction, number of wells in the model, and starting date of the simulation. This information is defined in the "RUNSPEC" section.

*Grid and Rock Properties*

The second step for developing a model is to define the number of grid cells in I, J, and K directions, dimensions of cells, the permeability of cells, and porosity of cells. This information is defined in the "GRID" section.

As the reservoir is heterogeneous it has different permeability and porosity in the I, J, and K directions.

*Fluid Properties*

The third step for developing a model is to define the concentration of oil and water at the surface, the formation volume factor, viscosity of water and oil, reservoir pressure, rock compressibility, and water compressibility. This information is defined in the "PROPS" section.

*Initial Conditions*

The fourth step for developing a model is to define initial reservoir pressure, saturation conditions, and water-oil contact. This information is defined in the "SOLUTION" section.

Production Schedule:

The last step for developing a model is to define the names of wells, their positions and groups, the completion period for each well, and specify the injector and producer controls. This information is defined in the "SCHEDULE" section.

Salinity limits and relative permeability:

The literature research revealed that the threshold limit for low saline waterflooding effects is between 500 and 5000 ppm [8]. As a result, the range of low saline waterflooding is kept within the threshold limit in this study. As a result, depending on the salt content, it is important to change the relative permeability for oil-water phases and the saturation endpoints for the modelling of low saline waterfloods. Therefore, the reservoir's wettability has a significant impact on low salinity. The following Corey model equations have been applied to produce the relative permeability and saturation profiles that depict oil-wet and water-wet conditions in the reservoir [9]:

$K_{rw} = S*^{N_w} + E_w$ (1)

$K_{ro} = (1 - S*)^{N_o} E_o$ (2)

$E_w = K_{rw}(S_{or})$ (3)

$E_o = K_{ro}(S_{wi})$ (4)

$S^* = \frac{S_w - S_{wi}}{1 - S_{wi} - S_{or}}$ (5)

$K_{rw}$ - Relative permeability to water

$K_{ro}$ - Relative permeability to oil

$N_w$ - Empirical constant for water

$N_o$ - Empirical constant for oil

$S^*$ - Normalized water saturation

$S_w$ - Water saturation

$S_{or}$ - Residual oil saturation

$S_{wi}$ - Irreducible water saturation

$E_w$ - Endpoint relative permeability for water

$E_o$ - Endpoint relative permeability for oil

To generate relative permeability curves the data used has been summarized in Table 1.

**Table 1.** Corey parameters for the base model [9].

| Oil Wet Conditions | | Water Wet Conditions | |
|---|---|---|---|
| **Parameters** | **Values** | **Parameters** | **Values** |
| $S_w$ | 0.3 | $S_w$ | 0.1 |
| $S_{wi}$ | 0.2 | $S_{wi}$ | 0.2 |
| $N_o$ | 3.0 | $N_o$ | 2 |
| $N_w$ | 3.0 | $N_w$ | 3 |
| $E_o$=$K_{ro}(S_{wi})$ | 0.5 | $E_o$=$K_{ro}(S_{wi})$ | 0.8 |
| $E_w$=$K_{rw}(S_{or})$ | 0.8 | Ew=$K_{rw}(S_{or})$ | 0.6 |

Figure 3 illustrates how varied residual oil saturation ($S_{or}$) during waterflooding results from altered wettability profiles.

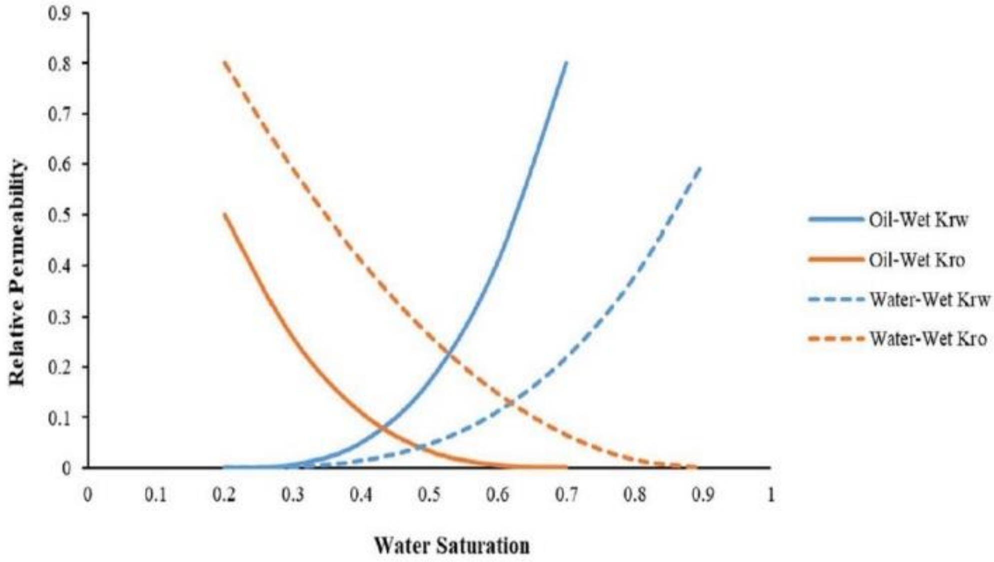


**Fig. 1** Relative permeability curves for oil-wet and water-wet conditions.

Additionally, rock wettability has a significant impact on the saturation endpoints for both water- and oil-wet systems. High water relative permeability, low oil relative permeability, and high residual oil saturation are the characteristics of an oil-wet reservoir. In an oil-wet reservoir, significant salty waterflooding results in low ultimate oil recovery. The cross-over point for the oil-water relative permeability curve intersects at a fraction below 0.5 water saturation. A water-wet reservoir, on the other hand, has high oil relative permeability, low residual oil saturation, and low water relative permeability. The convergence of the oil-water relative permeability curves may be shown in Figure 3 to be at 60% of water saturation. Thus, it is demonstrated in this situation that the eventual oil recovery is maximized [10,11].

## 5. RESULTS & DISCUSSIONS

The underlying reservoir model in this work was first simulated for continuous low salinity (LS) and high salinity (HS) water injection. After that, a sensitivity analysis for different well injection methods, including a direct line and a five-spot pattern, was carried out. For a total of five years, the simulation was run. In this study, primarily, two cases are simulated to inspect the effects of salinity on the behavior of oil-wet sandstone reservoirs. The two cases are defined as:

- Continuous injection of Low Saline (LS) water treated with magnetic field (1000 ppm)
- Continuous injection of High Saline (HS) water treated with magnetic field (45000 ppm)

*Oil Saturation Response*

According to the simulation's findings, low saline water injection produced a significant amount of oil. Whereas high saline water injection left almost 53% of residual oil behind. Saturation response of both high salinity waterflooding and low salinity waterflooding is represented in Figure 4 and 5 respectively.

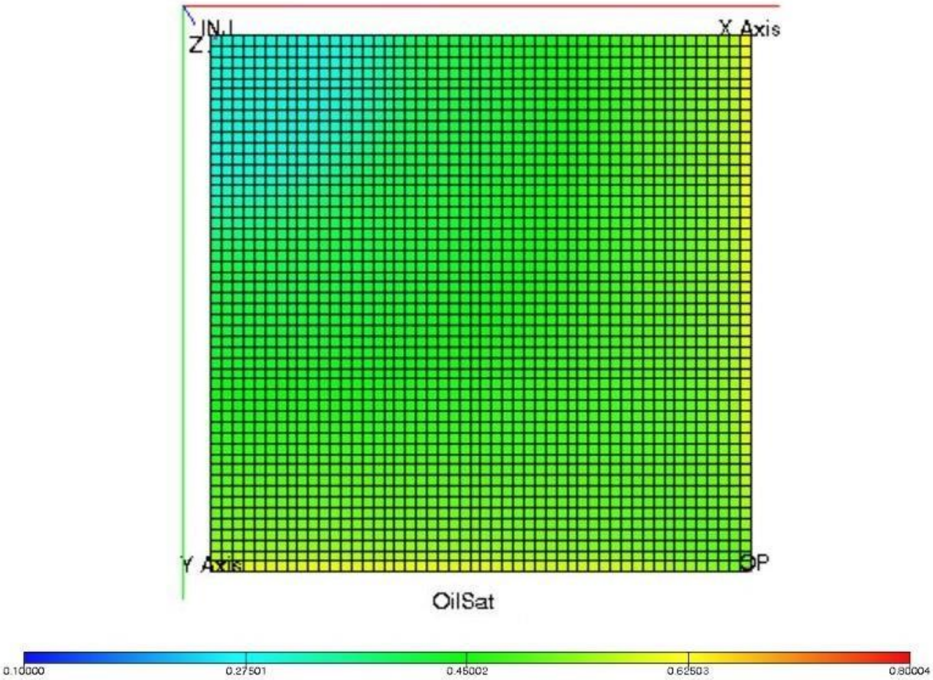


**Fig. 4** Saturation response over high saline waterflooding.

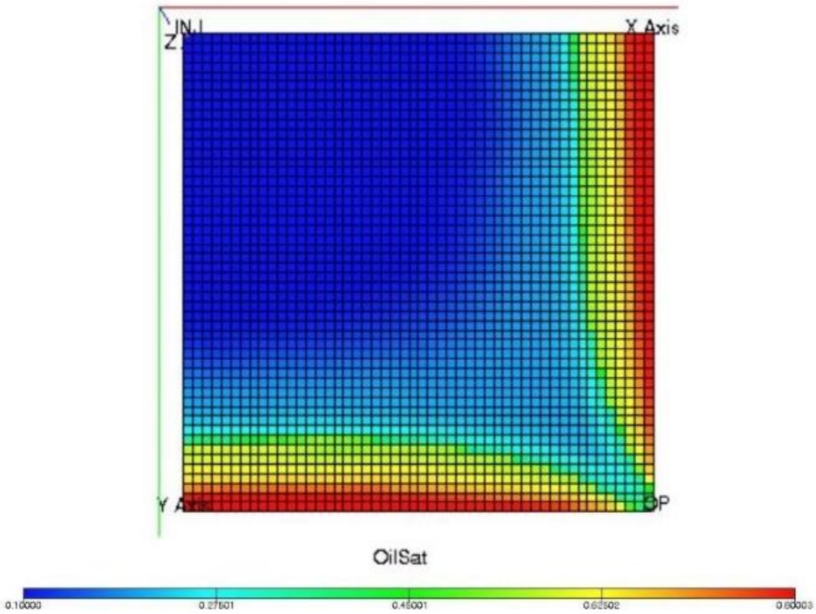


**Fig. 5** Saturation response over low saline waterflooding.

The wettability alteration is what caused the considerable oil displacement from the reservoir. Additionally, the clay particles are retained undistributed because the rock is held in an oil-wet condition, which contributes to the reduced displacement effectiveness in high saline water injection.

*Field Oil Production Rate*

Figure 6 shows that the oil production rate for both low- and high-saline waterflooding is constant for the first year at the controlled volume of 630 STB/Day.

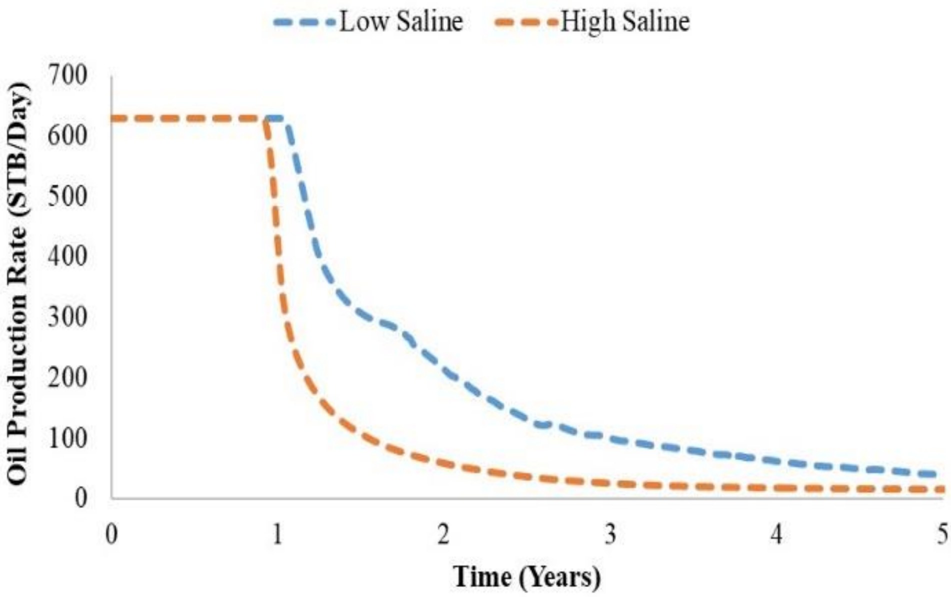


**Fig. 6** Oil production rate response for low and high saline waterflooding.

At the conclusion of the first year, the production rate tends to decline, and by the end of the second year, it has reached 100 STB/Day for the low saline water injection and 25 STB/Day for the high saline water injection.

Similar trends may be seen for the third, fourth-, and fifth-years' producing periods. The field production rates for low salinity and high salinity are 39 STB/Day and 15 STB/Day, respectively, at the end of the fifth year.

*Field Cumulative Oil Production with Oil Recovery*

The rates of oil production have a direct impact on the total amount of oil produced. Since oil is producing quite rapidly when low saline water is injected than when high saline water is injected, the cumulative oil production obtained during low saline waterflooding is also higher, coming in at 0.45 MMSTB at the end of five years as opposed to 0.3 MMSTB for the high saline flooding. Figure 7 displays a summary of the total oil production during the past five years.

After five years of cumulative oil production, the recovery of oil acquired through the injection of low saline water is around 80%, whereas the recovery of oil gained through the injection of high saline water is 57%. When the water's salinity is changed when the wettability is changed from oil-wet to water-wet, the amount of recovered oil increases, which reduces the saturation of remaining oil.

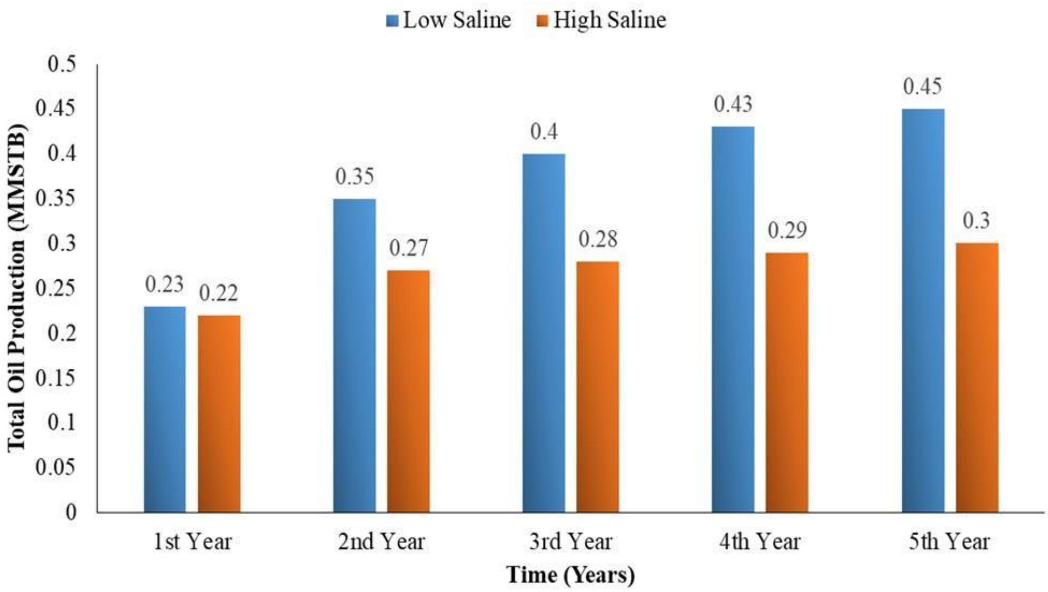


**Fig. 7** Cumulative oil production response for low and high saline waterflooding.

## 6. CONCLUSIONS

Based on simulation results, the following conclusions have been drawn:

- Low saline water injection demonstrated superior oil recovery performance compared to high saline water injection, leaving significantly less residual oil in the reservoir.
- Wettability alteration from oil-wet to water-wet conditions played a critical role in enhancing oil displacement during low saline water injection.
- The results showed that the salinity threshold limit determines whether the water-flooding process for an oil-wet reservoir is successful, and we saw that low salinity values prove to be a successful technique to enhance oil recovery and decrease water mobility in comparison to high salinity.
- At the conclusion of five years, the cumulative oil production obtained during low saline waterflooding is also better, peaking in at 0.45 MMSTB compared to 0.3 MMSTB for the high saline flooding. Additionally, a five-spot design produces 0.43 MMSTB of total oil production, compared to 0.45 MMSTB for a direct line drive.
- The results underscore the significant role of water salinity in influencing oil recovery. The lower salinity of LS water, combined with magnetic field treatment, enhanced wettability alteration and limited the redistribution of clay particles, improving oil displacement.

**REFERENCES**

[1] Ahmed, Tarek. 2006. Reservoir Engineering Handbook. United States of America: Gulf Professional Publishing.

[2] Abubaker H. Alagorni, Zulkefli Bin Yaacob, and Abdurahman H. Nour. 2015. "An Overview of Oil Production Stages: Enhanced Oil Recovery Techniques and Nitrogen Injection." International Journal of Science and Development,

[3] Cobb, James T. Smith and William M. 1997. Waterflooding. United States of America: Petroleum Technology Transfer Council, Midwest Office.

[4] Sagala, Allan Katende and Farad. 2019. "A Critical review of Low Salinity Waterflooding: Mechanism, Laboratory and Field Application." Journal of Molecular Liquids,

[5] Bernard, G. G. 1967. "Effect of Floodwater Salinity on Recovery Of Oil from Cores Containing Clays." SPE California Regional Meeting, 26-27 October, Los Angeles, California.

[6] Yogesh Kumar Suman, Ezeddin Shirif, Hussameldin Ibrahim, Abdulsalam Ala-Ktiwi. 2014. "Evaluation of Low Saline “Smart Water” Enhanced Oil Recovery in Light Oil Reservoirs." World Journal of Engineering and Technology.

[7] Guo-Qing Tang, Norman R Morrow,. 1999. "Influence of brine composition and fines migration on crude oil/brine/rock interactions and oil recovery." Journal of Petroleum Science and Engineering.

[8] McGuire PL, Chatham JR, Paskvan FK, Sommer DM, Carini FH. 2005. "Low salinity oil recovery: an exciting new EOR opportunity for Alaska’s north slope." SPE western regional meeting. Society of Petroleum Engineers.

[9] Behrenbruch P, Goda HM. 2006. "Two-phase relative permeability prediction: a comparison of the modified brooks-corey methodology with a new carman-kozeny based flow formulation." SPE Asia Pacific Oil & Gas conference and exhibition. Society of Petroleum Engineers.

[10] Anderson, W.G. 1987. "Wettability Literature Survey-Part 6: The Effects of Wettability on Waterflooding." J Pet Technol 39, p.1605–1622.

[11] Zhang Y, Morrow NR. 2006. "Comparison of secondary and tertiary recovery with change in injection brine composition for crude oil/sandstone combinations." SPE/DOE symposium on improved oil recovery. Society of Petroleum Engineers.