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Mechanism Investigation of Low Salinity Water Injection Technique from a view of Numerical Stimulation Based on Experimental Data in Carbonate Reservoir

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ABSTRACT

Low salinity water injection (LSWI) is gaining popularity as an enhanced oil recovery technique in secondary and tertiary injection systems. Through contrasting newly documented significant displacement histories, this work hopes to gain insight into the process by which LSWI impacts carbonate recovery. This article describes ocean circulation competition and suggests two approaches for comparing the LSWI circulation across time using the UTCHEM model. The parameters of volume permeability (end and demand curves) and pressure capillary curve (residual oil concentration) were assessed for their sensitivity to LSWI. According to the findings, alterations to the water cutoff are still thought to have a significant role in how quickly LSWI recovers. Carbonate has proved beneficial for oil recovery and pressure reduction. Good data correlation needs endpoint, sample, residual oil volume, and permeability calibration. What's more, oil-related permeability parameters, as opposed to water-related permeability parameters, are often in charge of LSWI-enhanced oil recovery. This paper's findings shed light on a hitherto mysterious IOR process and provide a potential technical model for estimating oil recovery. Multi-factor analysis of historical LSWI cycle symmetry (UTCHEM). The effective matching of recovery factor and pressure drop data shows that moisture fluctuation influences LSWI's effect on carbonate reservoirs' recovery factor. Improperly comparing simulation models and experimental data over time improves LSWI oil recovery. This work gives us a better knowledge of EOR and a model for predicting oil recovery.

Keywords: Mechanism, Low salinity water injection, Carbonate reservoir, Historical experimental data; Numerical simulation

1. Introduction

Carbon deposits are a significant obstacle to oil recovery due to high fracture density and rock moisture, ranging from mixed to soil. Following Low Salinity Water Injection (LSWI), one of the newly approved Enhanced Oil Recovery (IOR) procedures, the rock's moisture content is expected to change to a more hydrophilic state. Light to medium crude oil can be efficiently transferred using LSWI technology. The technology has the advantage of easy integration into oil-bearing systems, readily available and inexpensive water, and low capital requirements. Operating costs are lower than other IOR methods.

Innovative water injection and advanced ion management are two terms that refer to the same technology. In the laboratory and, to a lesser extent, in the field, LSWI has been found to enhance oil recovery from carbonate rocks. Some scientists suspect that changes in humidity are the only way LSWI affects oil recovery from carbon, while others believe it is essential. Therefore, research on the chemistry of unrefined salt-salt rocks (COBR) in porous media is ongoing. Previous ideas linked moisture changes to low salinity water in the soil, which is not the case in carbonates, so the effect of LSWI on oil recovery from them has not been well considered. However, laboratory-scale studies using direct injection and core flooding have been conducted to investigate the effects of LSWI on carbonate recovery (Hidayat, 2022).

In the literature, there are many experimental works on various tests such as direct dip test, capillary pressure and zeta potential, especially on carbonate rocks. Seawater and saline were employed as injection fluids in large-scale flooding studies under varying circumstances. In an effort to determine the primary mechanism that improves LSWI oil recovery, Egbe et al, (2021).

Three decisive ions (Ca2+, Mg2+, and SO42") in seawater change the surface wettability of limestone and calcareous rocks to wet high water by chemical mechanism, for instance, ion exchange/reaction with the rock surface. Due to seawater's multiple ion exchange (MIE) effects, carbonate reservoir rocks can enhance oil recovery by adding different versions of sulfate to SW, as suggested by Alizadeh (2022). On the other hand, other studies have changed the three ions to keep the salinity close to seawater levels. Spontaneous injection experiments were performed with limestone carbonates in the Middle East. However, they observed no change or improvement in oil recovery, contradicting the assumed MIE process. It was also found that with other types of ions (borate and phosphate ions), Substituting sulfate ions in seawater can significantly improve oil recovery for both ions in the primary flood test.

Injection of excess sulfate ions into seawater seems to result in localized formation, as sulfate readily interacts with calcium ions; a localized Formation leads to precipitation, which leads to oil displacement. In addition, it has been shown to soften formation water with high salinity (for instance, removal of Ca2+, Mg2+) and Enhance oil recovery (Esene, 2018). On the other hand, when we eliminated divalent cations, we saw no change in the relative humidity.

In a different research direction, Esene et al. showed that the interaction of simple brine increases in the presence of sulfate. This interaction is essential; they observed that brines with sulfate could increase oil recovery. Seawater irrigation and water production (slightly saline water) can also be used as EOR methods, indirectly related to anhydrite dissolution. However, it has been shown that desalination is more effective in enhancing oil recovery than sulfate addition, leading to controversy.

The role of sulfate in this EOR technique. Using zeta potential measurements, the surface of the limestone becomes less oily as the continuous transition from FW to SW dilutes the SW. Surface charge changes. The effect of temperature was studied as follows changes in the moisture content of carbonate rocks caused by low salinity and conclusions on the rational mechanism. The change in humidity is a combined effect of surface charge and chargeable ions, as suggested by Egbe.

These moisture changes are not necessary. On the other hand, they show that the oil/brine interaction has a more significant effect on the depth of oil recovery than the zeta potential of the rock/brine. It can be considered that the main problem of the LSWI determination of the excellent mechanism behind the EOR is the over-emphasis of the geochemical processes observed at the rock/brine interface, although this happens regardless of oil and reserves; therefore, it leads to the investigation of the polar structure of the oil as the role of an essential part of the urination behavior.

Researchers suggest better mechanistic models for inclusion in reservoir simulators due to a growing knowledge of wettability change processes. In earlier investigations, models that altered the wettability of rocks depended on external factors like salinity. Wettability was altered by altering the relative permeability and capillary pressure parameters in relation to this variable. Improved models were created that considered geochemical interactions between injected brines and carbonate rocks, such as ion-exchange processes and dissolution/precipitation reactions.

According to Hidayat et al., This study focuses on two aspects of LSWI in carbonates: I quantify the formation of microdispersion in different salinites through fluid-water interactions, and (ii) enhancing recovery in carbonate particles. Two crude oil samples were selected, one with a high tendency to produce microdispersion and the other with a low tendency to produce microdispersion. The microdispersion was filtered from the crude oil to obtain a third sample (crude oil) before the crude oil was used in the main experiment.

The high and low salinity waters are injected into the large carbonate reservoirs of the second and third series. If the main process of LSWI oil recovery in carbonate rocks is the generation of microdispersion, we predict that the crude oil recovery factor will be greater than that of the other two samples (negative oil and treated oil).

1.1 Objectives of the research

Investigation of crude oil/low salinity interactions during low salinity EOR. Investigate crude oil/desalination interactions (moisture changes) about reservoir rocks. Research on the Effective Mechanism of Action of Carbonate Storage. Application of intelligent water EOR and its application analysis in one of the carbon reservoirs. Use the business simulator to choose the best location for innovative water treatment.

1.2 Experimental design of the study

Systematically addressing the effects of the principal physical attributes and chemical composition of the materials utilized is essential for the research of brine flooding in carbonate reservoirs—the molecular and ionic interactions of inexpensive salts and oils. Water flow behavior and recovery are influenced by how salt rock and crude oil salt interact. Black-box Corfludex tests show us the effects of several processes occurring within the core, yet these are independent of one another. The first section of this experimental approach details the phenomena associated with liquid-liquid interactions, including the reactions of crude oil reservoirs to brines of varying salinities (including the dilution of generated water and consumed water) and exhibiting effective dispersion.

Having calculated the percentage of each crude oil dissolved in water, we can now order the oils from least to most diluted. The reaction of crude oil with four salts of varying salinities was studied. Based on their respective rankings, two crude oils were selected: one with a high propensity to generate microdispersions in water, and another with a low propensity to do so. Three experiments were conducted using the crude oil chosen in the first section to determine the crude oil's water transfer capability (base water). The CF-1 main flooding test included aging particles in tanks of crude oil M2, which is a readily solid oil with excellent dispersion. Oil based on Crude Oil M2t, processed by removing surface-applied natural elements, was the basis for Coreflood #3 (CF-3), an older version of the second Coreflood (Experiment CF-2). This oil had a low propensity to create micro-fractions.

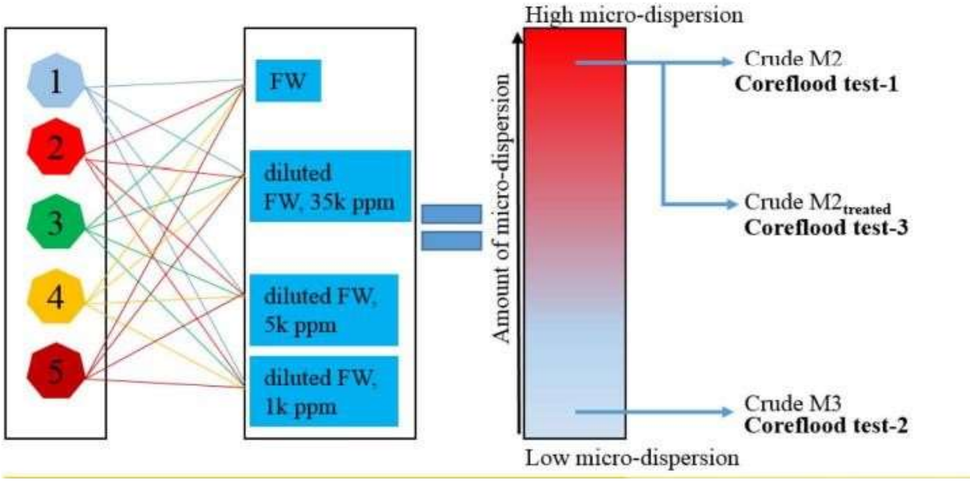


Figure 1: Test design for detecting water microdispersion in crude oils at varying salt concentrations Microdispersion testing of crude oils at varying salt concentrations

2.1 Method for determining crude oil's propensity for micro-dispersion

A series of contact tests were performed, exposing crude oil samples to brines ranging in salinity from formation brine (high salinity) to 200-fold diluted formation brine to estimate the possibility that the crude oil samples would mix into micro-dispersions.

The tests were carried out by dissolving NaCl in a Middle Eastern oil reserve. Sodium bicarbonate, water, and a combination of calcium and magnesium chloride. Four different types of brine solutions exist, each with different salinity.

Use the values shown in Figure 1 (FW = 208,600 pmm, diluted FW 1 = 35,000 ppm, diluted FW 2 = 5,000 ppm, and diluted FW 3 = 1,000 ppm)(AlHammadi, 2018.). In-house contact tests accurately portray the dynamic between low-salinity brine and crude oils. The phenomena of low-salinity currents and resident oil in pores can be simulated. Karl Fischer titration was applied to crude oil with a touch of water to measure the amount of surplus water, establishing the degree of microdispersion. A correlation between improved oil recovery and core flood tests is desirable. This approach of characterization is helpful because crude oils are prone to microdispersion. They are used to order reservoir systems based on the screening process results, 8 being subjected to a variety of crude oils that fall within the same density and viscosity categories (AlHammadi,2018).

After diluting the salt by a factor of 100, the two chosen positive crude oil samples remained unable to produce micro-dispersions. They were sent to separate individuals for analysis: Microdispersion and the size distribution of the exposed salt in molten brine. In light of this, the approach used in this study (Determined g the benefits of low dispersion) may be used to assess appropriate systems, such as the implementation of heavy crude oil and low salinity particles, using appropriate tests. The usual outcome of combining crude oil with brines of varying salinities is seen in Figure 2. It is worth noting that the results of the micro-dispersion studies will be given as a ratio.

$The\ bound\ water\ content\ of\ contacted\ oil$ refers to the water already present in the oil before it was put through the contact test and was not removed by centrifugation or other physical means.

Micro-dispersions are formed in a specific crude oil (Crude-M2). The Crude-M3 sample was chosen to illustrate a low-performing oil in micro-dispersion formation. Figure 1 shows that when the salinity of the contacting brines was decreased, Crude-M2 and Crude-M3 reacted differently. More microdispersion was generated as the salinity of the contacting brine decreased (Adila et al., 2022). A decrease in salinity below 5000 ppm is associated with a micro-dispersion increase. However, the formation of negligible amounts of micro-dispersion was seen when Crude-M3 was exposed to low salinity brines. Note that a micro-dispersion ratio of less than 3 indicates that the crude oil is not high-quality. Preparing crude M2 by treating it in desalted water before primary flooding allowed us to conduct a mechanical examination of the key routes leading to LSWI-enhanced oil recovery.

That is scientific trials. The original crude oil had microdispersion removed, yielding a sample (Crude-M2t) free of the minute oil components typically seen in microdispersion crude. A battery of experiments showed that crude-M2t that had been assembled and treated did not have a propensity to create a tiny dispersion, meaning that oil recovery was not boosted even at high LSWI (Egbe,2021).

Three different crude oils were analyzed and chosen to assess the importance of micro-dispersion formation in oil recovery using LSWI. Based on the fluid/fluid interaction testing results, three core flood experiments were conducted to examine the correlation between the two further. The Crude-M2 was used for the first Coreflood (CF#1) (high propensity to form micro-dispersion). Also, low micro-dispersion Crude-M3 and Crude-M2t were used for core floods (CF) two and three. Oil recovery from CF#1 should be most significant relative to the other two corefloods if micro-dispersion is the primary process.

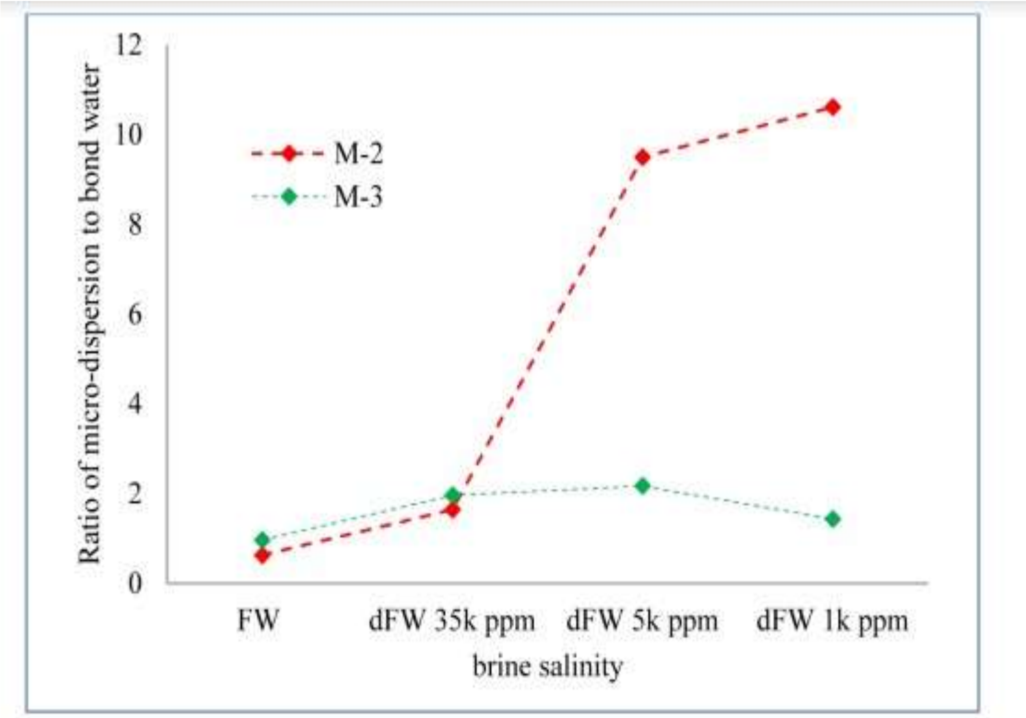


Figure 2: Findings from a fluid-fluid characterization experiment looking at how different saltwater concentrations affected different types of crude oil.

1.3 Experimental materials and methods

The three long-term reservoirs studied in this study all came from a single carbon reservoir in the Middle East. Each base is approximately 30 centimeters (cm) long and 3.81 centimeters (cm) in diameter. In Table 1, you can see the results of permeability and permeability of the particles used in this study. Images taken by ESEM showed cores made of calcite crystals, further evidence that the rocks were indeed carbonates. To ensure that the base material of the non-woven composition is stable, we conduct a tracer examination.

	Cf#1	CF#2	CF#3
Length in cm	30.	28	30
Diameter in cm	3.7	3.7	3.7
Porosity, frac.	0.268	0.267	0.272
Karine, MD	2.60	2.24	2.24
Swi, frac	0.09	0.08	0.1

Table 1 reservoir core samples

Four previously used brines were injected in secondary and tertiary modes with FW = 208,600 ppm and 200 times diluted FW LS = 1,000 ppm. Brine permeability was measured by injecting FW brine into each of the three cores, which was also employed as a secondary high salinity FW mode. Table 2 displays the synthetic brine's viscosities at high temperatures.

Letter name	High salinity brine	Low salinity brine
TDS, ppm	208,600	1000

Table 2

Crude oil samples were used in the investigation; They were collected from reserves in the Middle East. The results of the analysis of SARA (Saturates, Aromatics, Resins, Asphaltene) of oil samples are shown in Table 3. A capillary viscometer was used to measure the viscosity of crude oil. This table shows how crude oil treatment changed the SARA content of crude M2. Polar compounds are closely bound to resin and tar content, and changes in those components may suggest that polar substances are involved in the formation of microdispersion. Crude oil is filtered to remove solid or suspended particles before it is used to form a pre-water concentrate and moisture recovery.

Crude Id	Saturate,%wt	Aromatics,%wt	Resins,%wt	Asphaltene,%wt.
M1	62	31	5.4	0.8
M2	62	31	7.1	0.04
M2t	67	26	5.6	0.5

Table 3 shows the properties of Crude oil.

1.4 Experimental procedure

The injection fluid for a core flood is stored in one of four tanks on the rig. A back pressure regulator (BPR) was used to maintain a constant pressure of 1000 psi at the vent's base. Schematic of the simple flooding mechanism employed in this investigation (Figure 3). The core samples were aged for 21 days by injecting an equal amount of crude oil through the core after the initial water and mineral oil saturation. We kept an eye on the DP of each core as they aged and injected crude oil at a rate of 1.5 pv per week until the DP of the entire core was stable. We measured an average oil saturation of 0.91 across all three tests. Because the oil's relative permeability decreases with age, a mixture of wet and dry conditions can develop after initial water saturation. Apply a water flow rate of 4 cc/h at 80°C and 1000 psi to force the base displacement. For a long time, the second stage of injection consisted of high-salt water, and the third stage of injection consisted of low-salt water. The DP curve and oil recovery were tracked in real time as the test progressed. The pH and ion content of the primary wastewater were also analyzed as potential indicators of rock-water-aquifer interactions. When oil production ceases, high-salt water injection also ceases. Due to the lack of oil in the primary effluent, we tested three pump drives at 50, 70, and 80 cc/h for capillary end effects. The same three-needle system is used to inject salt water. Experiments can be run with cores under the same initial conditions to directly evaluate the enhanced oil recovery of low salinity to decrease High Level oil volume, shedding light on the advantages of low salinity over high salinity.

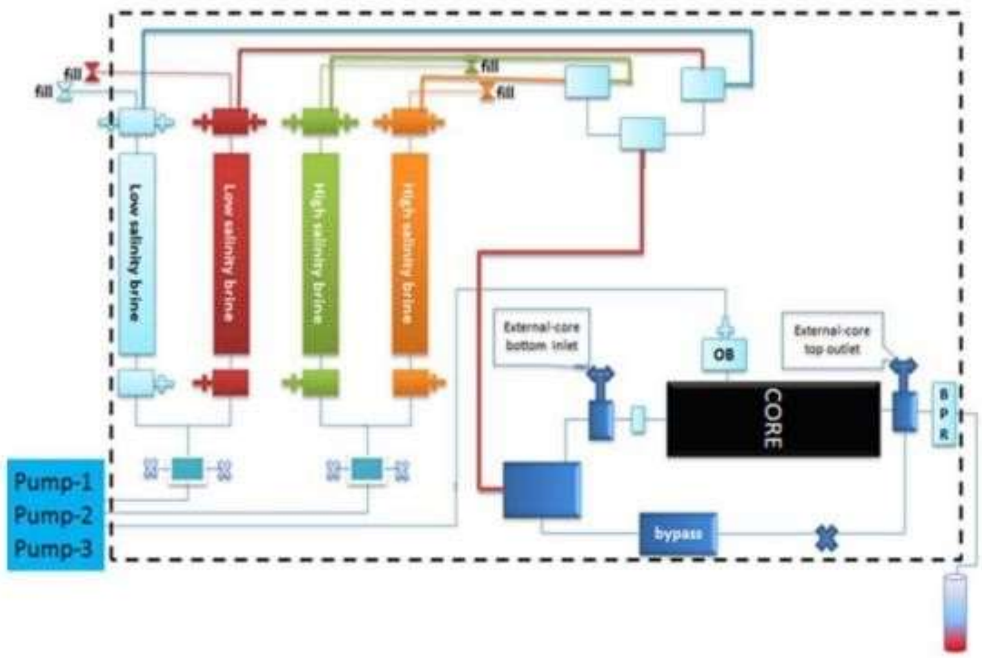


Figure 3. diagram of coreflood rig

1.5 Results

1.5.1 Secondary low salinity water injection

At a rate of 4 cc/h, inject hypersaline was released. During the second salinity water flood, the PVI WBTs of all three pellets were about 0.7. Three embryos were placed in high-salt water to aid healing (Figure 4). This block's oil recovery is comparable to crude-M2 (high propensity to develop microdispersions) and crude-M3 (low tendency to microdispersions). However, following treatment with low salt water to remove fractions and naturally reactive molecules associated with crude oil M2, the crude oil differs from natural crude oil (crude oil M2) by a small amount: less. The oil recovery rate compared to crude oil demonstrates that crude oil has a different moisture content than pre-M2 crude oil. However, the pore shape of the cores may vary significantly, which might account for the observed overall discrepancies. It should be noted that the secondary hypersalinity was undertaken to increase the salinity of the Sor system (residual oil saturation), and this research aimed to describe the LSWI process at greater levels. The ultimate oil recovery was identical when brine was added in all three main experiments, indicating that these tests had a high LSWI.

The flow rate used during a salinity flood is the same as the stocking rate (1 ft/day). It is more realistic to estimate the effects of a low salinity flood during a high-water level flood if artifacts from the second flood persist. The end capillary effect is one of the laboratory artifacts that can occur during low flow coreflood studies. Although an extended baseline model was used to minimize the effects of capillary action, pump flooding (high flow rate injection) occurred after successive saline injections. The oil balance in the core was established using three different pump flood flow rates, and the results of oil recovery and injection hole size are shown in Figure 5. 50cc/h, 70cc/h and 80cc/h are relevant flow rates. Injection continued until 0.5 pore diameter, at which point the oil in the core was completely submerged in brine and the flow rate returned to 4 cc/h.

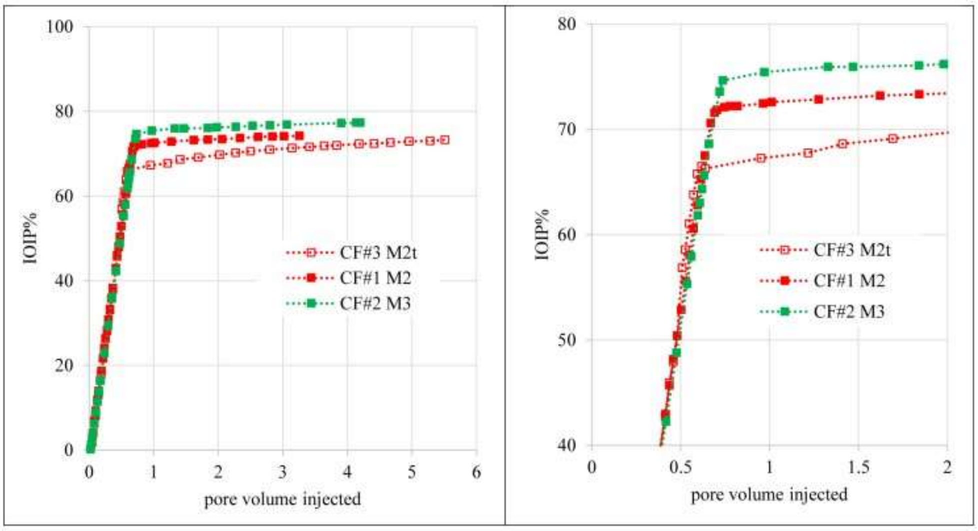


Figure 4 graph showing oil recovery for a long time of injecting water with a high salinity

Although changes in baseline and moisture levels can affect hydroponic systems, high water levels in hydroponic systems are equivalent to the effects of late growth and low oil yields on oil yield curves. However, the embryos used in this study showed signs of sensitivity to salt intake. Figure 4 explores the concept of basic integrity. A piston-type displacement controls fluid velocity, which manifests itself as a delayed secondary explosion. This trend was confirmed by conducting follow-up studies to learn more about the flow temperature of liquid dispersions in porous media. Lithium chloride was added to the water as part of the tracer test. Lithium tracers are traditionally used to measure the degree of interstitial variation. Once the base water of formation #1 is fully saturated, brine is introduced to dissolve the formation (flooding sequence). First, the hole block 2 is drilled, followed by the primary injection of formation water to drain the lithium formation water (flooding sequence). Since the injection rate of the two-phase main liquid is 4 cc/hour, corresponding flood tests are performed at this rate. A lithium tracer with a pore size of 0.85 can pass through the sample and enter the test area, blocking after 1.2 PVI (as shown in Figure 6). During the displacement phase of the tracer test, the PVI was 0.86, confirming the tracer flow rates in both layers, indicating that the void formation has reached water efficiency.

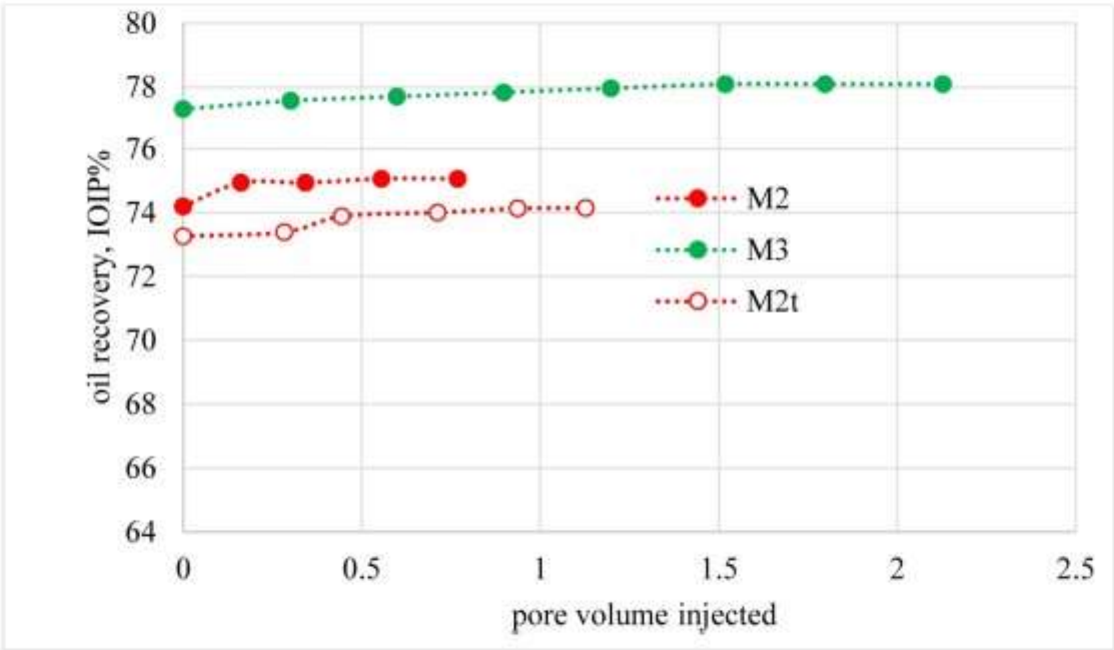


Figure 5 :0 PV in this graph shows the end of the primary flow rate (4 cc/hr) during a flood powered by high salinity water injection.

Tracer results from this investigation provide evidence that the particles used have a stable pore structure. This position requires the use of two-phase injection, which in turn requires moving water in increments of 0.7 PVI. Adding the initial water concentration (0.1) to the pore size of 0.7, the PVI improvement of 0.85 of the tracers corresponds to this period. Therefore, depending on the initial humidity, the displacement pattern does not change much.

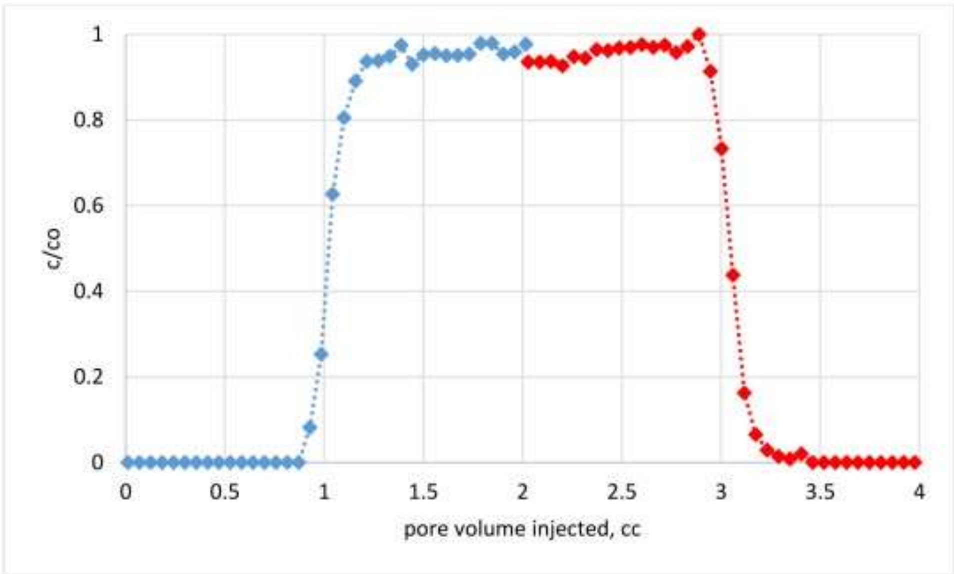


Figure 6: The results of the core homogeneity test on the lithium concentration profile (normalized to the initial lithium concentration)

1.5.2 Injection of Tertiary Water with Low Salinity

After the high brine is injected, the low brine is injected first to absorb the remaining oil. If microdispersion formation is the primary process for LSWI EOR, crude M2 is expected to respond well to the technology, but crude M3 and crude M2t will have a negative impact. The result is shown in Figure 7.

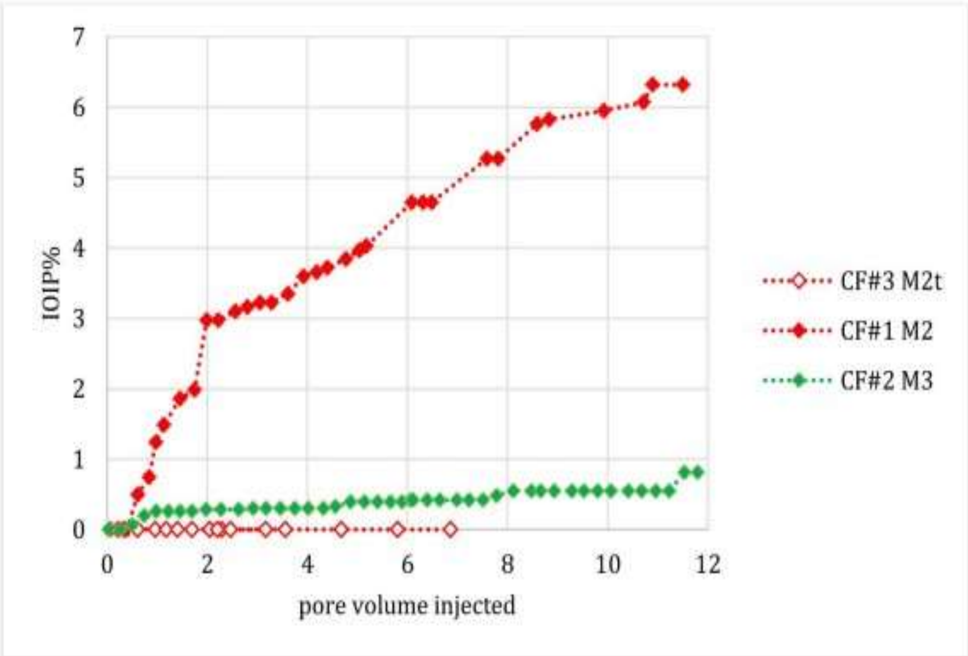


Figure 7: Recovering Oil While Injecting Low-Salinity Water

As a third step, it is more common to introduce brine into the carbon system. Cr Crude M2 improved oil recovery by 6.3% in a flood test. However, when Crude-M3 and Crude M2D were used in carbonate systems, high salinity water did not affect recovery. The results obtained for crude oil with a low dispersion capacity resulting from high conditions indicate that the carbon structure responds well to flooding with low salinity water. The main crude oil flooding tests M2 and M3 showed that neither crude oil nor crude oil resulted in better recovery, indicating a direct effect of crude oil production capacity on LSWI performance. The carefully designed experiments in this study show that the main reason for enhanced oil recovery is the formation of a microdispersion that acts as an off switch during crude oil processing. The well-dispersed elements of M2 are removed, thereby reducing the effectiveness of the introduction of brine (treatment). The Discussion and Results section describes the benefits of saline injections for fat recovery. Additionally, other processes that have not been identified as best practices in previous work should be explored to gain a common understanding of key LSWI systems.

1.5.3 Effluent analysis via ion chromatography and core pH analysis.

In this case, carefully planned experiments demonstrate that microdispersion production is a critical factor for LSWI-assisted increased oil recovery in carbon systems. Enhanced oil recovery may be affected by a number of geological phenomena that have been studied in the literature.. These geochemical processes, including dissolution, pH changes, and sulfate exchange, also occur in the absence of petroleum. To better understand the processes involved in geochemical processes, wastewater is often analyzed for its salt content. pH equals ionic content. The primary effluent is analyzed using pH and ion chromatography (IC). Since the interaction of rock with brine can be observed from the pH of the resulting brine, we started our studies using this parameter. As shown in Figure Fi, the pH values of the prepared brine were obtained at the beginning, middle, and end of the third primary tank of the third sequence of low-salinity water flooding. Figure 8. When diluted 200 times, the pH of raw brine is 6.5, which is the pH at which brine is formed.

In the middle, the dissolution of calcite (and dissolution of CaCO3 to form HCO3) increases the pH during the three LSWIs. In LSWI, the outflow of the concentration of ions in the effluent is a diluted version of the concentration of ions in the brine, so the ratio of ions in both streams is the same, so the ions are considered inactive in sodium (Na+) and chloride (Cl-) carbonate systems. Ion distributions expressed as ratios provide more information. Instead of plotting the ion concentration, you should express it as a ratio, such as C/Co. Therefore, C/Co cannot record the formation time of low and high salt during the Tertiary process. The ratio of ions in brine is constant regardless of salinity. On the left side of Figure 9 are curves showing the ratio of calcium and magnesium to sodium. In addition, the ratio of sulfate to chloride concentrations increases as the profile changes. This evidence suggests that the increase may be caused by the leaching of minerals from the rocks.

Additionally, the ratio of sulfate to chloride increases with increasing pore volume. The injection of LSWI, which reaches a maximum in both pore sizes, followed by ionization and dissolution of anhydrite on the rock surface, may be responsible for increased sulfur content. The mineral was analyzed to determine the source of the Tertiary water with low salinity identified during the injection.

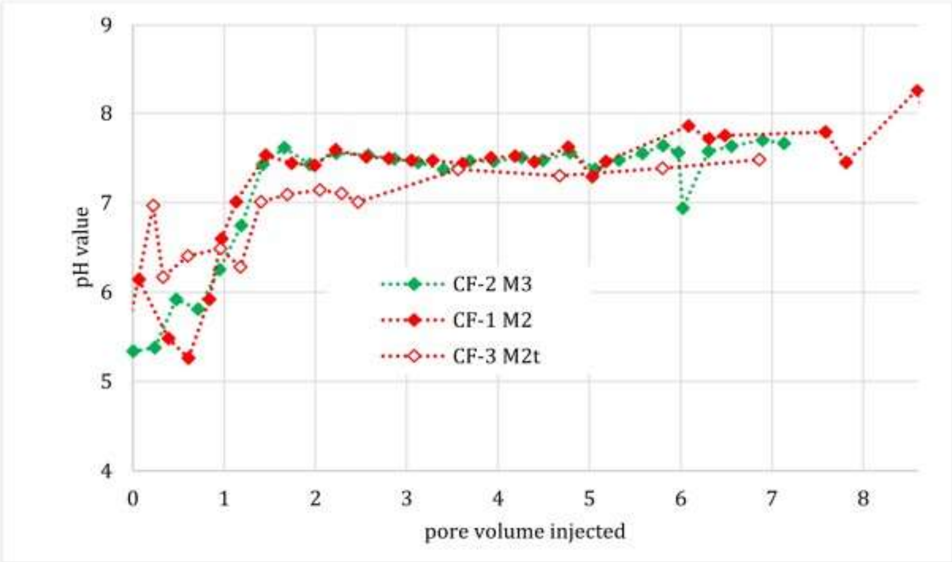


Figure 8: When low-salinity tertiary water is injected into a core test, the pH of the effluent water changes.

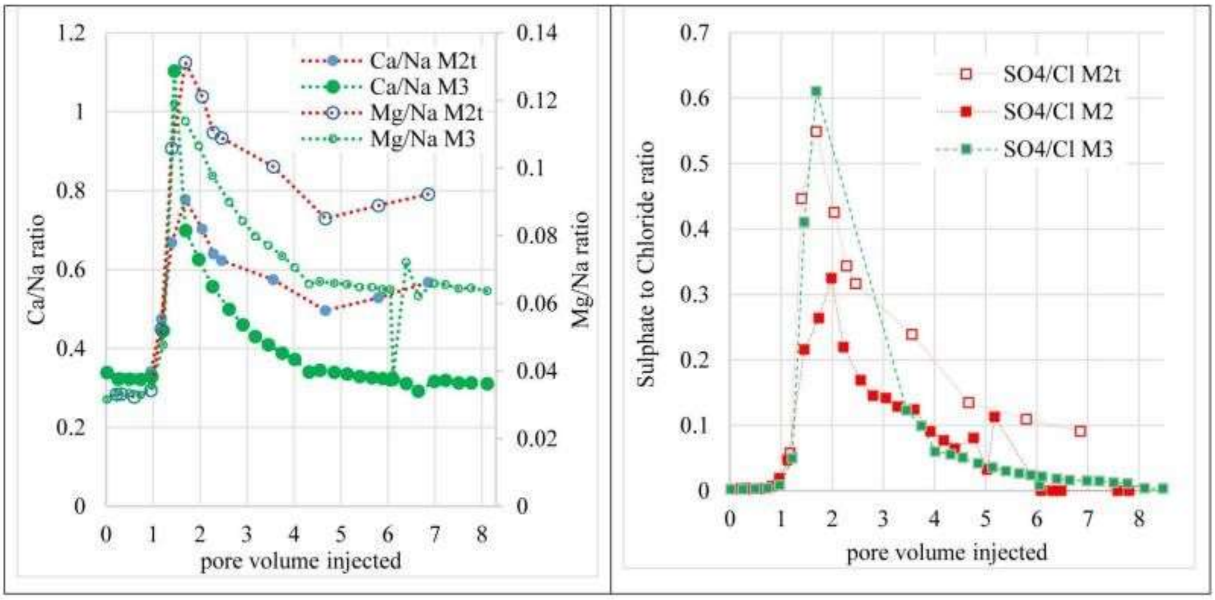


Figure 9: Changes in Ca and Mg concentrations during tertiary low salinity water injection are seen on the left plot. Figure depicting effluent SO4/Cl shift during tertiary low salinity water injection is accurate.

Mineral dissolution, pH increase, and in-situ creation of sulfate ions were all detected across all three core flood experiments. However, only one experiment was able to react to tertiary LSWI. That is to say; the three corefloods are roughly comparable in terms of the amount to which key geochemical processes occurred. In contrast, no correlation between geochemical shifts and LSWI oil recovery was seen. Consequently, it is assumed that the release of oil from the rock would not be affected by these interactions between the rock and brine surface. This means that these activities are a secondary effect of LSWI and not the primary event itself.

1.6 Discussion and conclusion

Over the last two decades, much study has been conducted on the efficiency of brackish water injection systems. All sides believe that altering humidity is beneficial to oil output. However, contradictory conclusions and misconceptions emerged when the core reasons for these precipitation changes were investigated. Because of the effect of geochemistry and salinity intrusion, rock-salt contact is considered the primary mechanism. The relationship between ion exchange, pH change, and bilayer swelling were initially studied in a deposition system, although contradicting occurrences doubted their supremacy. Previous research using LSWI in carbonate rocks employed various rock types but discovered considerably enhanced oil recovery. Knowledge gathered from depositional systems has been inadequate when applied to carbonate systems. As shown by this research, establishing which oil components contribute to the release of target oil species should be the first goal.

By planning and executing several innovative experiments, such as liquid-liquid contact measurements and core investigations, this research takes a novel approach to address a recurring issue. Based on the microdispersion test findings, two crude oils were chosen: one with high micro disparity and one with low microdisperity. Three preliminary tests were carried out, and the findings revealed that oil strength is the sole, adjustable variable for LSWI increased oil recovery. The key conclusion of the research done here to establish the primary mechanism of LSWI, as shown in Figure 10, was an improvement in oil recovery of 6.3% by employing bulk crude oil (crude oil-M2). Furthermore, no other oil recovery results were detected in the refined oil after removing the microdispersion. Based on these data, we predict a significant and persistent link between IOR and oil attractiveness, resulting in minimal dispersion. For more insight, the ion analysis and pH measurements of groundwater were performed, and it was discovered that a similar degree of geochemical reactions occurs in all groundwaters, regardless of high or low recovery; thus, this geochemical interaction reported in the literature cannot be controlled—additional oil recovery.

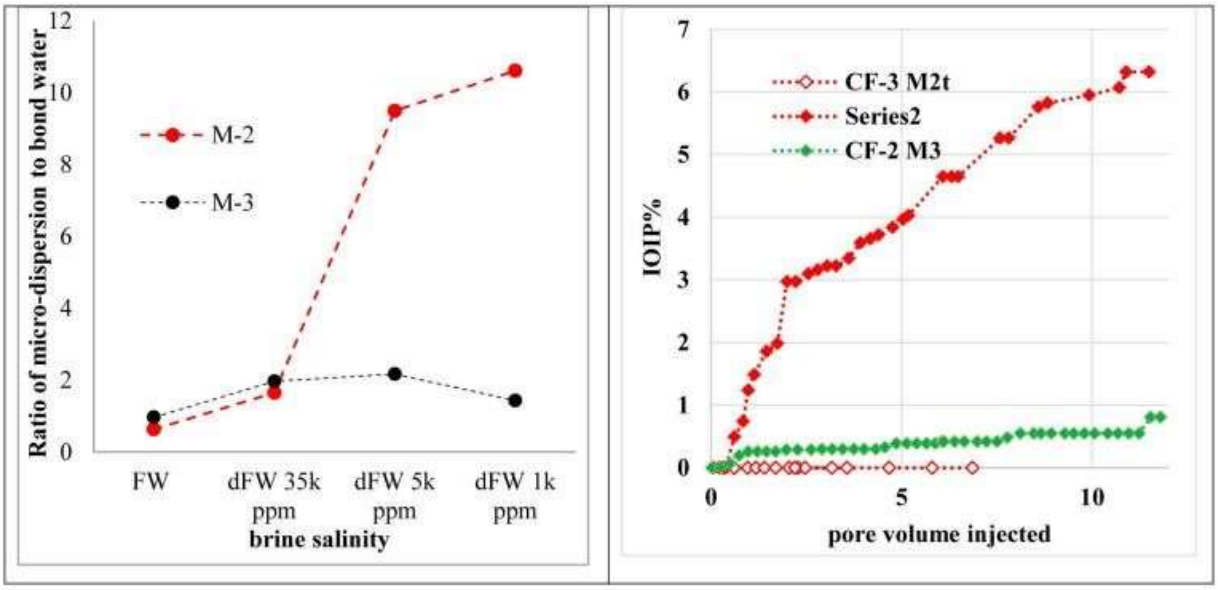
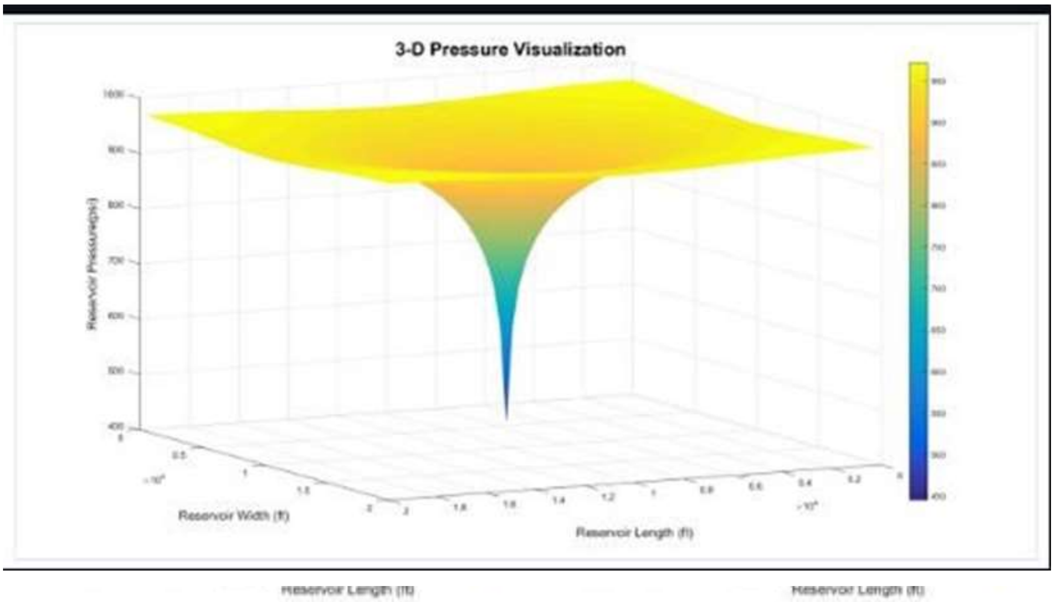


Figure 10—Left plot displays Crude-M2 and Crude-M3 micro-dispersion data. The right-hand plot shows tertiary LSWI's increased oil recovery. CF#3 uses Crude-M2t.

3D model stimulation results



Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to affect the work reported in this paper.

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Appendix

The 'InputSHP.dat' file will be read in the following lines. This file provides the soil hydraulic information for the right values, the beginning values for the searching process, limits of existence domain for soil characteristics, and a variety of other relevant details.

```
%======================================================================
====
% Reading the inputSHP file.
cFileName=[cDataPath '\InputSHP.dat'];
f20=fopen(cFileName,'r');
nsoiltype=3;
for i=1:5; fgetl(f20);end
shpcorrect=zeros(nsoiltype,6); %pre
for insoil=1:nsoiltype
    shpcorrect(insoil,:)=fscanf(f20,'%f',6); fgetl(f20);
end
fgetl(f20);fgetl(f20);
shpini=zeros(nsoiltype,6); %pre
for inmat=1:nsoiltype; stextall{inmat}=fgetl(f20); end %capture soil
texture
for inmat=1:nsoiltype;
    shpini(inmat,:)=fscanf(f20,'%f',6); fgetl(f20); %capture shp
end
fgetl(f20);
shpborder(1,1:6)=fscanf(f20,'%f%f%f%f%f%f\n',6);
shpborder(2,1:6)=fscanf(f20,'%f%f%f%f%f%f\n',6);
f10=fopen('LEVEL_01.DIR','w');
fprintf(f10,'%s',cDataPath);
fclose(f10); %closing level_01.dir
fclose(f20); %closing inputSHP
clear f10 f20;
```

After then, information about time is shown. Everyone was told when the warm-up time had concluded and when the process of upgrading would start. inc keeps track of the amount of time, measured in days, that passes between various updates. The prim variable stores the amount of time that elapses between tinitial and the first update. At long last, ult gathers the last day's worth of data.

```
tinitial=365; %-->-->-->-->--> Initial time after the warm-up period
inc=7;        %-->-->-->-->-->-->--> MODIFY IF REQUIRED
ult=1460;     %-->-->-->-->-->-->--> MODIFY IF REQUIRED
prim=7;       %-->-->-->-->-->-->--> MODIFY IF REQUIRED
DATIMES=[tinitial tinitial+prim:inc:ult];
NDATIMES=length(DATIMES)-1;
```

In the subsequent stage, geometrical information may be adjusted, including the number of nodes, the placement of observation sites, and a variety of other parameters.

```
% x. Geometrical information
NNODES=111;
dist=1; %distance between nodes in cms
xref=[-15;-55;-75]; m=length(xref);
x(1:NNODES,1)=0:-dist:-110;
nmat=1;
mat(1:NNODES,1)=1; %only 1 material.
nref(m)=0;          %preallocation
for j=1:m; nref(j)=find(x==xref(j)); end
ipick(NNODES,1)=0; ipick(nref,1)=1;
```

In addition to what was said above, the program can successfully operate in a variety of environments and kinds of soil. This is when the climate-soil feedback loop begins.

There are a total of four distinct climate-change scenarios. Users have the ability to generate new climate files while maintaining the same format.

```
%% Beginning of loop clim-soil
for iclima=4        %======================== LOOP OF CLIMATES

%======================================================================
====


    % 2. Selecting the correct Atmospher file
    switch iclima
        case 1; cFileNameAtm=[cDataPath '\ATMOSPH4YR_1_AZ.IN'];
        case 2; cFileNameAtm=[cDataPath '\ATMOSPH4YR_2_ID.IN'];
        case 3; cFileNameAtm=[cDataPath '\ATMOSPH4YR_3_IN.IN'];
        case 4; cFileNameAtm=[cDataPath '\ATMOSPH4YR_4_TX.IN'];
    end
    for isoil=1:2    %======================== LOOP OF SOIL TYPES


%======================================================================
```

In the lines that follow, the code parses the observation data in light of the prevailing weather patterns and soil composition. A technique for fabricating data is shown in Valdes-Abellan et al.

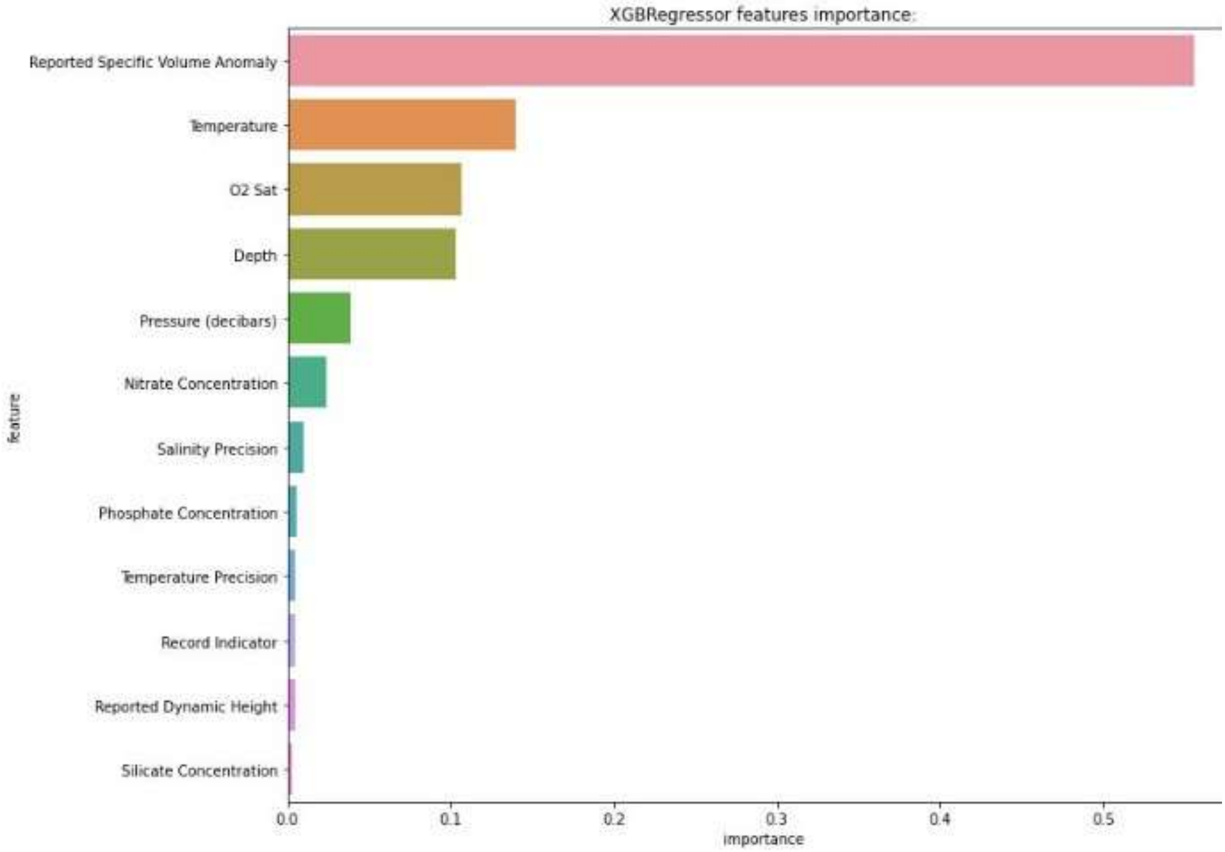
```
        % 1. Read observations
        file=['wsynthetic_C' num2str(iclima) '_S' num2str(isoil) ];
        load(file);
        wobs=wsin; clear wsin
        [ntobs,nsensor,~]=size(wobs);        %m is number of
obsrevation depths
        tobs=1:ntobs;

        %========================================
        % Selection of pdtf (ALWAYS ROSSETA IN THIS CODE)
        shpaver=shpini(isoil,:);
```

```
        %
        %==========================================================
        %% SAVING RESULTS
        % =============================================
        %  Saving observation in file
        filename = ['wout_obs.txt'];
        cFileName=[cDataPath '\' filename];
        f23= fopen(cFileName, 'w');
        line='    Day';
        for mm=1:m;  line=[line '          ' num2str(abs(xref(mm)))
'cm']; end
        l1=find(tobs==DATIMES(1));
        l2=find(tobs==DATIMES(NDATIMES+1));
        wobsaver(l2-l1+1,m+1)=0;
        wobsaver(1:l2-l1+1,1)=tobs(l1:l2);
        for mm=1:m
            wobsaver(1:l2-l1+1,mm+1)=mean(wobs(l1:l2,:,mm),2);
        end
        fprintf(f23,line);  fprintf(f23, '\n');
        fprintf(f23, '%8.2f%12.4f%12.4f%12.4f\n', wobsaver');
        fclose (f23); clear f23;
        % =============================================
        %  Saving simulation in file
        filename = ['wout_sim.txt'];
        cFileName=[cDataPath '\' filename];
        f23= fopen(cFileName, 'w');
        line='    Day';
        for mm=1:m;  line=[line '          ' num2str(abs(xref(mm)))
'cm'];  end
        wsimuaver=wobsaver(1,:);  %copy the first line from obs to
simu. It's the initial time
        wsimuaver(DATIMES(NDATIMES+1)-DATIMES(1)+1,m+1)=0;
%preallocation
        wsimuaver(2:DATIMES(NDATIMES+1)-DATIMES(1)+1,1)=wsimu(:,1,1);
%copy times;
        for mm=1:m
            logi=wsimu(:,2:end,mm)>0; % to not consider error
simulations
            wsimuaver(2:DATIMES(NDATIMES+1)-
DATIMES(1)+1,mm+1)=sum(wsimu(:,2:end,mm),2)./sum(logi,2);
        end
        fprintf(f23,line);  fprintf(f23, '\n');
        fprintf(f23, '%8.2f%12.4f%12.4f%12.4f\n', wsimuaver');
        fclose (f23); clear f23;


%==================================================================
====
        % 8. Saving results
        if generation==1
            line=['results\I05_dualv2_C' num2str(iclima) '-S'
num2str(isoil) '-Inc_' num2str(inc) '-Discre_' num2str(dist)];
        else
            line=['results\I05_dualv2_gen2_C' num2str(iclima) '-S'
num2str(isoil)];
        end
        save(line,'shpevol2','shpstd','rsquare','rmse',
'nse','rsquarefut','rmsefut','nsefut')
        fclose all;
    end      % end of soil type
end          % end of climate type
disp('The end!!!!!')
```

Results



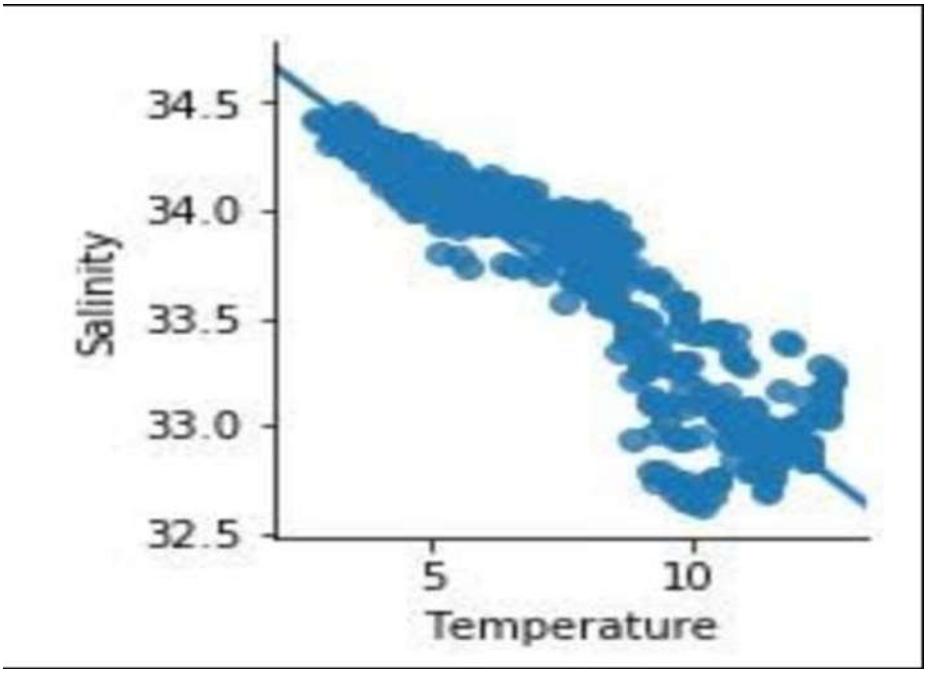
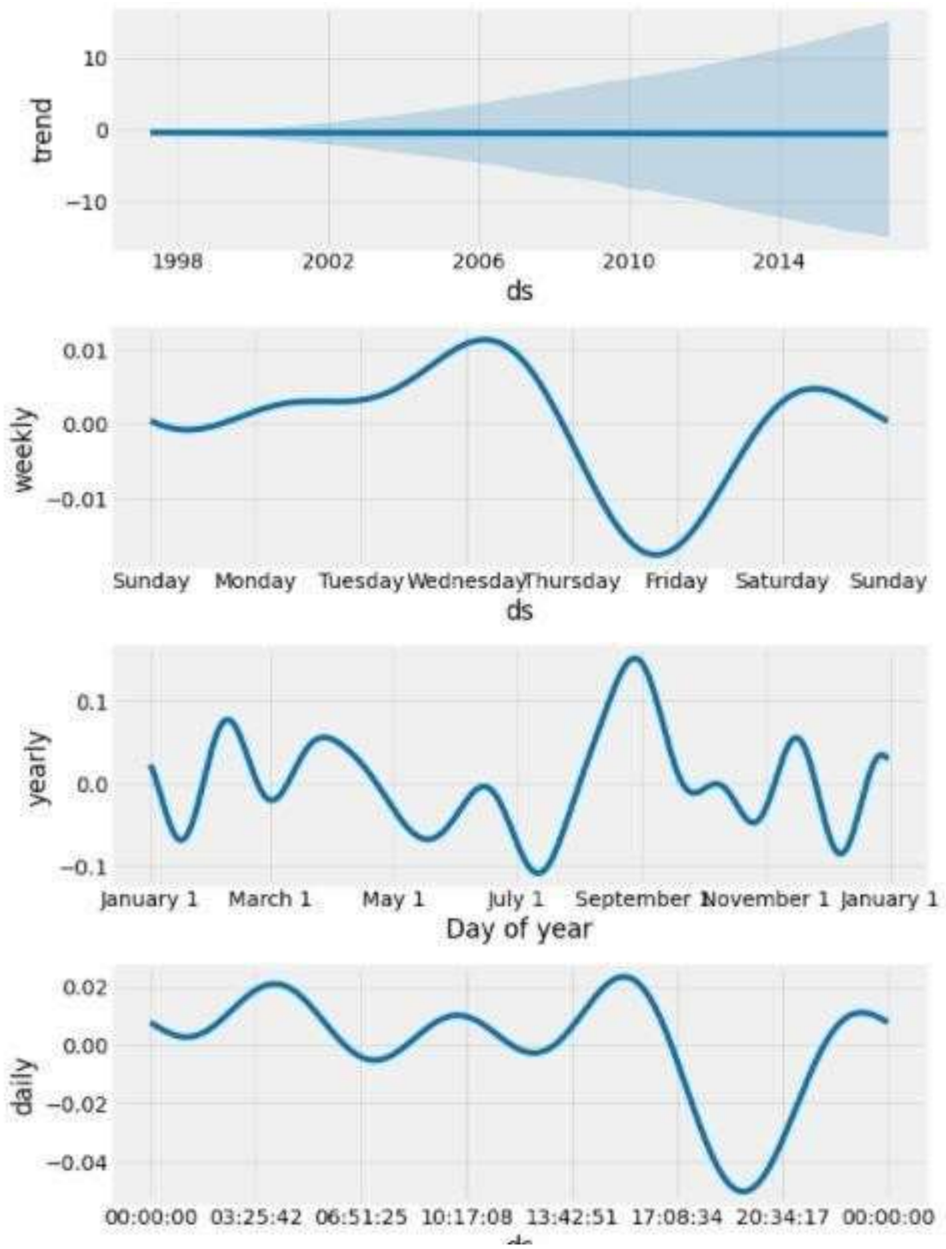
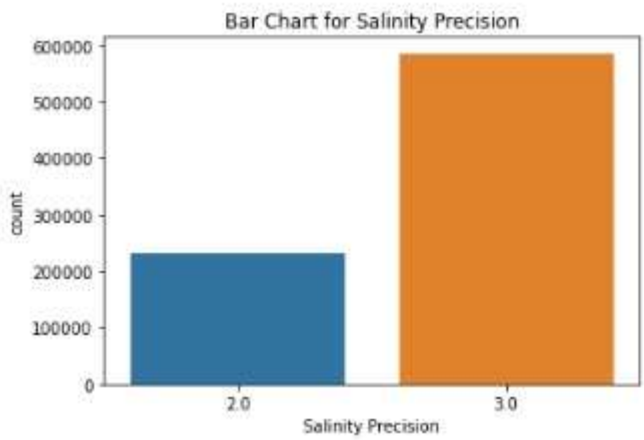


Figure 1: salinity vs Temperature graph


trend
10
0
−10
1998
2002
2006
2010
2014
ds
weekly
0.01
0.00
−0.01
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
ds
yearly
0.1
0.0
−0.1
January 1
March 1
May 1
July 1
September 1
November 1
January 1
Day of year
daily
0.02
0.00
−0.02
−0.04
00:00:00
03:25:42
06:51:25
10:17:08
13:42:51
17:08:34
20:34:17
00:00:00


Bar Chart for Salinity Precision
count
600000
500000
400000
300000
200000
100000
0
2.0
3.0
Salinity Precision