Scaling simulation resulting from mixing predicted model between Mishrif formation water and different waters injection in Basrah oil field, southern Iraq

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Abstract

Dependable scale prediction is of critical importance in the selection of suitable injection water and the development of an effective scale management strategy. The present study focuses on the Mishrif reservoir in the West Qurna oilfield. In this reservoir, we use compositional modeling to understand the interplay between multiphase flow, phase behavior, and geochemical reactions under reservoir and injection conditions relevant to the field. The numerical model PHREEQC was used to simulate the compatibility between Mishrif formation water with three various kinds of surface waters: Sea Water (SW), Euphrates River Water (ERW), and the Main Outfall Drain Water (MODW), and predict the amount of possible scaling results from the mixing of different ratios under reservoir conditions. The chemical compositions of the Mishrif waters are classified as Brine water due to the high value of Ca^{2+} and Na^{2+} concentration. The waters from the sea, Main Drain Outfall, and the Euphrates River are classified as slightly Brackish waters. All the studied water samples were classified as sodium chloride type (NaCl) due to the increase of evaporation processes, aside from agricultural and domestic activities. The hydrogeochemical facies of the present water samples are fall in NaCl, except in the Mishrif formation water, which is located between NaCl and MixCaMgCl. Scaling prediction models of mixing show that calcium carbonate (CaCO_3) and Barite (BaSO_4) is expected to cause serious problems in the Mishrif reservoir when all types of waters mix in different ratios in the absence of scale inhibitors, whereas the model results revealed no problems in Celestite, Aragonite, and Strontianite scales due to their minor precipitation behavior through mixing. Gypsum, Sederite, and Anhydrite tend to dissolve when mixing all types of surface waters in different ratios because of a low saturation index. The simulation results show that the best ratios to mix sea water is 90–10% formation water, all ratios to mix Main Drain Outfall water, and 70–30 and 90–10% when mixing Euphrates River water with Mishrif formation water. Chemical inhibitions treatment preferred to be implemented to reduce the carbonate scales during/after water flooding.

Keywords Waterflooding · Scaling · Basra oilfield · Mishrif formation · Saturation ration, Iraq

Introduction

Water flooding is one of the choice methods used to enhance and increase oil production from the oil/gas reservoirs to support reservoir pressure (Jreou 2012), and/or to push oil towards the producer well. However, a new method for waterflood injection is being established. Injection water with significantly lower salinity or presence of ions than sea water or surface water has been shown to have beneficial

effects on oil recovery (Morrow and Buckley 2011). The problem associated with dissolved undesirable minerals and gas in the water injection that affected this method (Erany 2016).

The mineralogy problem is usually caused by chemical reactions of the water injection with the sensitive clay, which swells or becomes dislodged and blocks the reservoir pores. Water quality can be affected by several types of contaminants, including suspended solids, scale, bacteria, corrosion products, and marine organisms. Chemical and biological analyses can provide a useful indicator of future incompatibility, corrosion, and bacterial problems (Mitchell and Bowyer 1982).

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Precipitation of mineral scales causes many problems in oil and gas production operations, such as formation damage, production losses, increased workload for producers and injectors, poor injection water quality, and equipment failure due to under-deposit corrosion. Geochemical reactions between fluids and carbonate rocks can cause significant scaling in and around injection and production wells, leading to high operating costs. The most common mineral scales are sulfate- and carbonate-based minerals. However, scale problems are not limited to these minerals, and there have been recent reports of unusual scale types, such as zinc and lead sulfides (Collins and Jordan 2003).

The aims of this project were to simulate the compatibility between Mishrif formation water with three various kinds of surface waters: Sea water (SW), Euphrates River (ERW), and the Main Outfall Drain water (MODW), and to predict the amount of possible scaling results from the mixing of different ratios by using a hydrogeochemical PHREEQC Vr 3, 2015 computer software program to calculate mineral saturation indices. This calculation is based upon the Pitzer theory of electrolytes, which is generally believed to be the best approach to calculate the effect of high temperature, pressure, and total dissolved solids (TDS) in the composition of activity coefficients using Pitzer equations (Pitzer 1991).

Although the South Oil Company in Basrah province may become accustomed to the use of Qarmat Ali water for injections, it is also hoped that the company can use the Main Outfall Drain water. Sea water is commonly used as a source of injecting water, especially in offshore field areas, as in the Basrah oil fields. However, injecting natural sea water is recognized to have no significant effects on the oil field recovery. The high content of hardness ions, such as SO_4^{2-} and CO_3^{2-} , are believed to induce more scale depositions when in contact with formation water. Costly treatments and environmental issues are a constraint when applying conventional water injections.

Starting in 1975, the Mishrif reservoir in the West Qurna Oilfield started to produce without any energy supply, and most producers ceased to produce because of low reservoir pressure. Therefore, a water injection pilot was conducted starting in 2010, and the expanded water injection began in 2013. After 2 years of water injections, several producers are back to production, and the production rate of several wells is increasing significantly. However, a number of problems have arisen, the most significant of which being scaling issues. Geochemical reactions between fluids and carbonate rocks can cause significant scaling in and around injection and production wells, leading to high operating costs (Atiaa and Handhel 2009).

In order to manage this problem, this study highlights the hydrogeochemistry of the oilfield water and the expected damage as a result of sea water, Euphrates River water, and Main Outfall Drain water as injections to the Mishrif

reservoir by using a hydrogeochemical PHREEQC Vr 3, 2015 computer software program to calculate mineral saturation indices. This calculation is based upon the Pitzer theory of electrolytes, which is generally believed to be the best approach to calculate the effect of high temperature, pressure, and TDS on the composition of activity coefficients using Pitzer equations (Pitzer 1991).

Mechanisms of scaling and types

The main sources of oil field scales result from the mixing of incompatible waters, as precipitation minerals could be found as an outcome of this process (Merdhah and Yassin 2008). A typical example of incompatible waters is sea water with a high concentration of SO_4^{2-} and low concentrations of Ca^{2+} , $\text{Ba}^{2+}/\text{Sr}^{2+}$, and formation waters with very low concentrations of SO_4^{2-} , but high concentrations of Ca^{2+} , Ba^{2+} and Sr^{2+} . The mixing of these waters, therefore, causes precipitation of CaSO_4 , BaSO_4 , and/or SrSO_4 (Paulo et al. 2001).

There are many types of scale-like sulfates, such as calcium sulfate (anhydrites, gypsum), barium sulfate (barite), strontium sulfate (celestite) and calcium carbonate (calcite, dolomite). Iron oxides, iron sulfides, and iron carbonates are the less common scales Table 1 (Moghadas et al. 2003). Calcium carbonate is the predominant scale deposition from natural waters, especially in cooling and heating systems (El-Said et al. 2009). Carbonate scales can impair production by blocking tubing and flow lines, fouling equipment, and concealing corrosion (Zhang et al. 2001). The variety of ions that exist in the formation and injection waters, such as Mg^{2+} , Ba^{2+} , Sr^{2+} , Mn^{2+} and SO_4^{2-} , can affect CaCO_3 growth rate (Akin and Lagerwerff 1965).

Factors affected the scaling precipitation

The total dissolved solids and pH affect the permeability of the main reservoir. Clay minerals (like kaolinite and Montmorellonite) are considered as the main reasons behind the damage of oil formations. They can affect negatively formation characteristics through their dispersion and swelling due to the changes of chemical characteristics of the contact water (Scheuerman and Bergersen 1989). Clay mineral types will vary in their influence on the permeability of the formation depending on the basic silica structure, which varies from mineral to another (Al-Mallah 2014).

Increasing the temperature may increase or decrease the solubility of minerals, depending on the nature of the system. For example, if the dissolution process is exothermic, then the solubility decreases with increased temperature; if endothermic, then the solubility increases with temperature. The factors that affect scale precipitation, deposition, and

Table 1 Most common oilfield scales (Moghadasi et al. 2003)

Scale name	Chemical formula	Primary variables
Calcium carbonate	CaCO ₃	Partial pressure of CO ₂ , temperature, total dissolved salts, pH
Calcium sulfates		
Gypsum	CaSO ₄ ·2H ₂ O	Temperature
Anhydrite	CaSO ₄	Pressure
Hemihydrate	CaSO ₄ ·H ₂ O	Total dissolved salts
Barium sulfate	BaSO ₄	Temperature, pressure
Strontium sulfate	SrSO ₄	Temperature, pressure, total dissolved salts
Iron compounds		
Ferrous carbonate	FeCO ₃	Corrosion
Ferrous sulfide	FeS	Dissolved gases
Ferrous hydroxide	Fe(OH) ₂	pH
Ferrous hydroxide	Fe(OH) ₃	

crystal growth are super saturation, temperature, pressure, ionic strength, evaporation, contact time, and pH (Burchette 1993).

Geological and stratigraphic setting

The Mishrif formation is considered as one of the main productive reservoirs in southern Iraq that comprises an important place into the stratigraphic column of the middle Cretaceous period. It reflects the continuous deposition on a shallow carbonate platform developed during the Upper Cenomanian to Early Turonian period (Al-Mohammad 2012). Petrographic study and microfacies analyses revealed five main sub-environments: shallow restricted, shallow open marine, shoal, Rudist biostrom, and deep marine environments. Following a geologic log interpretation and microfacies analysis, the Mishrif formation was subdivided into five reservoir units (mA, mB1-1, mB1-2, mB2-1, and mB2-2). These reservoir units are characterized by high total porosity [18]. Figure 1 shows the stratigraphic column of the South Iraq, Basrah region, with key source rocks, seals, and structural events (Al-Khafaji et al. 2017).

Methodology

The chemical composition of Mishrif formation water were taken from an internal report of the South Oil company (South Oil Company (SOC) 2012), aside from the surface water (sea water and Euphrates River water), and average physicochemical composition of five Main Drain Outfall stations (Table 2; Fig. 2) (Al-Mallah 2014). This was executed in order to evaluate the simulation compatibility between above surface waters with Mishrif formation water, and to predict the scaling precipitation, in addition to evaluating the mineral saturation indices, resulting from the mixing of

different ratios of injection waters and formation water under reservoir conditions.

A hydrogeochemical PHEEQC Vr 3, 2015 computer software program (South Oil Company (SOC) 2012), which was written in the C programming language, was used to calculate the mineral saturation indices using Pitzer equations for the calculation of the activity coefficients in highly saline waters (Pitzer 1991). Mathematically, it can be calculated through the following equation:

$$\text{Saturation indices (SI)} = \frac{IAP}{K_{sp}} \quad (1)$$

where product, K_{sp} is the equilibrium constant called solubility product, and IAP is the ion activity product. For example, in the case of gypsum dissolution, it would be

$$IAP = [Ca^{2+}][SO_4^{2-}] \quad (2)$$

where brackets denote activities.

Water is considered as an equilibrium with respect to a given mineral; when $IAP = K_{sp}$, the saturation index value is 0. Water is supersaturated and the mineral should precipitate when the saturation index is greater than 0. If the saturation index value less than 0, the water is undersaturated and the mineral should dissolve (of course, if the mineral is present in a solid phase in contact with the water) (South Oil Company (SOC) 2012).

Chemical composition of formation water, and present surface waters

The chemical composition of the Mishrif Formation water and all the present studied waters are shown in Table 2. All the present studied water samples are characterized by weak alkaline types. According to (Parkhurst and Appelo

Fig. 1 Stratigraphic column of South Iraq, Basrah region showing key source rocks, seals, and structural events (Al-Ameri et al. 2011)

Table 2 Basic characteristics of Mishrif formation water and present surface waters

Sample identification	Mishrif formation water	Arab Gulf Sea water	Euphrates water	Main Outfall Drain
Sampling date	16/07/2012	2013	2010	2012
Cations(mg/L)				
Na ⁺	62,093	13,358	166.4	2480
Ca ²⁺	2905	357	89.18	284
Mg ²⁺	422	1230	36.21	382
Fe ⁺	2	<0.1	<0.2	0.4
Ba ²⁺	4	<0.1	0.2	0.1
K ⁺	22,682	354		20
Sr	137	8	6	7
Anions (mg/L)				
Cl ⁻	119,565	22,583	219.9	2660
SO ₄ ²⁻	4075	3359	288.2	1440
HCO ₃ ⁻	415	130	162.3	210
CO ₃ ⁻	0	0	0	0
Br ⁻	849.8	0	0.53	89.38
Resistivity (ohm-meters)				
@75 °F	0.0467	0.166		1.05
TDS (mg/L)	212,296	41,379	7430	8104
T(C°)	87.7	25	25	26
PH	7.27	7.88	8.23	8.15

2013) Table 3, pH is considered as an important parameter to control the solubility of many salts in a system (Komatina 2004). Therefore, the results may have negative effects on the reservoir due to the deposition of carbonate components, which reduces the permeability.

The total dissolved solids of Mishrif formation water is classified as Brine water (high saline water) due to the high value of Ca²⁺ and Na²⁺ concentration, which increases the salinity. Sea water, Euphrates River water, and Main Drain Outfall water are shown to be slightly Brakish waters according to (Hem 2005), whereas it classified as Brakish water according to (Todd 2009), (Table 4).

Cation concentrations results Table 2, show that Sodium Na⁺ is predominant in Mishrif formation water because of the dissolution of halite and evaporate rocks under the reservoir conditions. In addition, all the oil fields contain more sodium than any other cations due to their marine origin (Collins 1975). Sodium concentration also is the main cation in all the present water samples, which reflects different anthropogenic sources, including industrial, domestic, and animal wastes (Freeze and Cherry 1982).

The anion concentration results reflect that Cl⁻ is the most common anion in Mishrif formation water, which reflects the presence of gypsum-bearing sulfate sedimentary rocks (Janardhana Raju et al. 2011). Main Drain Outfall water shows the same results as the Mishrif formation water, due to the percolation from the sewage and the results of

irrigation activities (Bhatia 2003). Sulfate SO₄²⁻ was the main anion in sea water and Euphrates River water because of the high salinity and leaching of industrial and domestic sewage, which led to an increase in its concentration (Ramkumar et al. 2010).

Stiff pattern diagram is one of the hydrogeochemical graphical analysis methods used to represent chemical analyses by four parallel axes; concentrations of cations are plotted to the left of the vertical zero axis, and anions are plotted to the right (Todd 2009). The studied water samples are illustrated in Fig. 3, in which all the patterns show that all studied water samples under NaCl emphasized increasing the evaporation processes and sewage of agricultural and domestic activities that resulted towards the water systems, in addition to increasing the weathering of magnesium and sodium sulfate minerals (Esmaeili and Moore 2012). Dissolution of evaporates and carbonate rocks under the reservoir condition will increase ion solubility in water formation, in addition to the presence of gypsum-bearing sulphate sedimentary rocks (Janardhana Raju et al. 2011).

Hydrochemical facies

Piper diagrams are a geochemical graphic analysis method used in surface and groundwater studies. They can assist in evaluating the mechanisms of flow and transport in addition to ascertaining paleoenvironmental information

Fig. 2 Study area location map

(Ghalib 2017). A piper diagram of the studied water samples is shown in Fig. 4, in which all present water samples fell under Sodium chloride type (NaCl), except in the Mishrif formation water, which was located between NaCl and

MixCaMgCl type, which represents $\text{Na}^+ - \text{K}^+ - \text{Cl}^- - \text{SO}_4^{2-}$. From the cationic and anionic triangular field of the piper diagram, Mishrif is observed to be located in the zone of sodium type with no dominate anion type.

Table 3 Classification of water quality depending on the value of the pH (Komatina 2004)

Value of pH	Water quality
> 3.5	Strongly acid
3.5–<5.5	Moderate acidic
5.5–<6.8	Weakly acidic
6.8–<7.2	Neutral
7.2–<8.5	Weakly alkaline
8.5 and more	Alkaline

Table 4 Classification of groundwater according to the TDS (mg/L)

According to Freeze and Cherry (1979)	
TDS	Water class
< 1000	Fresh water type
1,000–10,000	Brackish water type
10,000–100,000	Saline water type
> 100,000	Brine water type
According to Todd (2007)	
TDS	Water class
10–1000	Fresh water
1000–10,000	Slightly-Brackish water
10,000–100,000	Brackish water
> 100,000	Brine water

The hydrogeochemical facies that could be recognized from Fig. 7 show that Mishrif formation water falls under the mixed CaMgCl type, which suggests the dissolution of carbonate and evaporate minerals. In general, alkalis (Na + K) significantly dominate more than the alkali earth elements (Ca^{2+} and Mg^{2+}), and strong acids (Cl^- and SO_4^{2-}) dominate more than weak acids (CO_3^{2-} and HCO_3^-).

Results and discussion

The calculations of mineral saturation indices and the establishment of equilibrium conditions of selected minerals resulting from mixing sea water in Mishrif formation water with different mixing ratios under reservoir conditions are shown in Table 5 (Fig. 5). In general, the results show a supersaturation of Geothite, Dolomite, Calcite, Barite, Strontianite, and Celestite, whereas the predicted results show an undersaturation with Gypsum and Siderite in any mixing ratios between sea water and Mishrif formation water. Anhydrite saturation indices show a supersaturation of 10 and 30%, 90 and 70% of sea water and Mishrif Formation water, respectively. These changes to undersaturation when mixing 50, 70, 90% of Gulf Sea water, and 50, 30, 10% of Mishrif Formation water, respectively.

Table 6 shows scale probability depending on saturation ratio (South Oil Company (SOC) 2012). The scale-predicted model for mixing sea water and Mishrif Formation water reveals that only Geothite has a saturation ratio between 4.0 and 10.0, suggesting that scales will possibly precipitate. Dolomite, Barite, Calcite, and Aragonite were predicted to be supersaturated where these waters mixed, and these scales are unlikely or minor to precipitate due to the lower expected saturation ratios, which are between 1.0 and 4.0. Therefore, a periodic inhibition treatment should be carried out through mixing.

The mixing predicted model of the Euphrates River water injection in Mishrif Formation water tends to precipitate Geothite, Dolomite, Calcite, Aragonite, Barite, and Strontianite, with a decrease in their saturation ratio and an increase of the Euphrates River water ratio Table 7 (Fig. 6), in which all these scales are supersaturated under reservoir conditions. Celestite tends to precipitate through mixing 50% Euphrates River water with 50% Mishrif Formation water, then tends dissolve in 70 and 90% of Euphrates River water with 30 and 10% of Mishrif Formation water. Anhydrite scales results show an undersaturation when the two waters mix, in addition to Gypsum, Halite, and Siderite scales.

According to Table 6, the scale predicted model for mixing Euphrates River water and Mishrif Formation water shows the same results as when injecting sea water, as only Geothite has the possibility to precipitate. Dolomite, Calcite, Aragonite, and Barite were predicted to be supersaturated when these waters mixed, and these scales are unlikely or minor to precipitate. However, there was no problem with Strontianite, Celestite, and Anhydrite, as no inhibition treatment would be needed because no precipitation will be found.

Table 8 shows the results of the simulation mixing ratio results of injecting the Main Drain Outfall water in the Mishrif Formation. The predicted saturation index results from the mixing model show that Geothite, Dolomite, Calcite, Aragonite, Barite, Strontianite, and Celestite scales were supersaturated under all mixing ratios between Main Drain Outfall and Mishrif Formation waters, while a deposition of Gypsum and Siderite scales that could be predicted as an undersaturated condition of these scales was found in various mixing ratios under the reservoir condition (Fig. 7). Therefore, a high saturation ratio of Geothite-predicted scales will be possible, and a permanent inhibition treatment should be implemented. However, there is no need for Strontianite and Celestite scale inhibition treatment, due to their low saturation ratios, whereas Dolomite, Calcite, Aragonite, and Barite should undergo periodic inhibition treatments because their scales have an unlikely or minor occurrence to precipitate.

Fig. 3 Stiff diagram of present waters

Fig. 4 Piper diagram of water samples of the present study

Table 5 Predicted saturation index for all possible scales resulting from mixing between Mishrif formation water and Gulf sea water under reservoir conditions (software output)

Mixing ratio	Saturation indices of phases									
	Calcite (CaCO ₃)	Aragonite (CaCO ₃)	Dolomite (CaMg(CO ₃) ₂)	Celestite (SrCO ₃)	Gypsum (CaSO ₄ ·2H ₂ O)	Anhydrite (CaSO ₄)	Geothite (FeOOH)	Siderite (FeCO ₃)	Strontianite (SrCO ₃)	Barite (BaSO ₄)
Gulf Sea Water	0.32	0.18	1.57	− 0.58	− 0.67	− 0.95	7.75	− 2.45	− 0.9	0.36
Mishrif Water	1.83	1.72	3.4	0.53	− 0.02	0.34	8.23	− 2.7	0.67	1.23
10% Gulf Sea Water	1.84	1.72	3.54	0.54	− 0.001	0.31	8.33	− 2.58	0.68	1.29
30% Gulf Sea Water	1.65	1.53	3.38	0.43	− 0.1	0.09	8.39	− 2.49	0.53	1.27
50% Gulf Sea Water	1.44	1.32	3.16	0.29	− 0.2	− 0.14	8.41	− 2.42	0.37	1.25
70% Gulf Sea Water	1.19	1.05	2.83	0.12	− 0.32	− 0.39	8.39	− 2.36	0.15	1.19
90% Gulf Sea Water	0.76	0.62	2.22	− 0.17	− 0.49	− 0.7	8.2	− 2.36	− 0.29	0.99

Fig. 5 Saturation indices of the mixture of Mishrif Formation water and Sea water at the reservoir conditions

Table 6 The scale probability according to scale type and ratio (South Oil Company (SOC) 2012)

Saturation ratio (Vary by scale type)	Risk assessment
< 1.0 no need inhibition treatment	Scale under saturated, no precipitation
1.0–4.0 periodic inhibition treatment	Scale unlikely or a minor occurrence
4.0–10.0 periodic / permanent inhibition treatment	Scale possible
> 10.0 permanent inhibition treatment	Scale very likely

Table 7 Predicted scale tendency for all possible scales resulting from mixing between Mishrif formation water and Euphrates River water under reservoir conditions (software output)

Mixing ratio	Saturation indices of phases									
	Calcite (CaCO ₃)	Aragonite (CaCO ₃)	Dolomite (CaMg(CO ₃) ₂)	Celestite (SrCO ₃)	Gypsum (CaSO ₄ ·2H ₂ O)	Anhydrite (CaSO ₄)	Geothite (FeOOH)	Siderite (FeCO ₃)	Strontianite (SrCO ₃)	Barite (BaSO ₄)
Euphrates water	0.67	0.52	1.28	− 0.65	− 1.22	− 1.52	8.03	− 2.62	− 0.06	0.77
Mishrif Water	1.83	1.72	3.4	0.53	− 0.02	0.34	8.23	− 2.7	0.67	1.23
10% Euphrates water	1.84	1.72	3.45	0.52	− 0.03	0.28	8.33	− 2.6	0.68	1.27
30% Euphrates water	1.65	1.53	3.11	0.36	− 0.18	− 0.001	8.38	− 2.59	0.55	1.21
50% Euphrates water	1.44	1.32	2.7	0.16	− 0.36	− 0.32	8.41	− 2.6	0.41	1.13
70% Euphrates water	1.22	1.08	2.21	− 0.1	− 0.6	− 0.69	8.39	− 2.64	0.26	1.01
90% Euphrates water	0.89	0.75	1.51	− 0.5	− 0.98	− 1.21	8.26	− 2.74	0.02	0.79

Conclusion

- For the Mishrif formation using sea water for injection, the results of the scale prediction model show that the most common oilfield scales represented by carbonate and sulfate minerals had a possibility to precipitate. Anhydrite and gypsum is unlikely or a minor occurrence.
- Using Euphrates water in injections were found to generate the same results as the sea water prediction model. The carbonate and sulfate minerals were the main precipitated scales, whereas other predicted scales were not expected to cause major problems as they dissolved under reservoir conditions.

Fig. 6 Saturation indices of the mixture of Mishrif formation water and Euphrates River water at the reservoir conditions

Table 8 Predicted scale tendency for all possible scales resulting from mixing between Mishrif formation water and Main Drain water under reservoir conditions (software output)

Mixing ratio	Saturation indices of phases									
	Calcite (CaCO_3)	Aragonite (CaCO_3)	Dolomite ($\text{CaMg}(\text{CO}_3)_2$)	Celestite (SrCO_3)	Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)	Anhydrite (CaSO_4)	Geothite (FeOOH)	Siderite (FeCO_3)	Strontianite (SrCO_3)	Barite (BaSO_4)
Main Drain water	1.83	1.72	3.4	0.53	-0.02	0.34	8.23	-2.09	-0.31	0.71
Mishrif Water	1.75	1.64	3.3	0.48	-0.07	0.23	8.27	-2.7	0.67	1.23
10% Main Drain water	1.59	1.47	3.08	0.38	-0.15	0.02	8.33	-2.66	0.61	1.23
30% Main Drain water	1.43	1.3	2.85	0.26	-0.24	-0.2	8.39	-2.59	0.49	1.22
50% Main Drain water	1.26	1.12	2.6	0.13	-0.32	-0.41	8.42	-2.51	0.38	1.21
70% Main Drain water	1.04	0.9	2.32	-0.05	-0.37	-0.6	8.4	-2.4	0.24	1.2
90% Main Drain water	1.83	1.72	3.4	0.53	-0.02	0.34	8.23	-2.25	0.01	1.12

- Scaling simulation results of mixing Main Drain Outfall water with different ratios showed supersaturation and a possibility of precipitating calcite and barite minerals. However, the other predicted scales were not expected to cause major problems under reservoir conditions.
- Anhydrite, Gypsum, and Sederite scales in any mixing ratios showed no need for any inhibition treatments

because of a low saturation index while tending to be undersaturated.

- All the scale-predicting models of the surface water injection results revealed compatibility with formation water, with the consideration of implementing a chemical inhibition treatment through mixing to avoid or reduce Calcite and Barite scale precipitation.

Fig. 7 Saturation indices of the mixture of Mishrif formation water and Main Drain water the reservoir conditions

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