Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2017.20172

65 (2017) 117–124
February

Predicting scale formation in wastewater disposal well of Rag-e-Safid desalting unit No. 1

Masoud Bijani[a,*], Reza Mosayebi Behbahani[b], Jamshid Moghadasi[c]

[a]*Department of Petroleum Engineering, Omidiyeh Branch, Islamic Azad University, University Boulevard, Omidiyeh, Iran, Tel. +989176264790; email: m.bijani1368@gmail.com*
[b]*Department of Gas Engineering, Petroleum University of Technology, Kut Abdollah, Near Imam Ali Square, Ahvaz-Abadan Expressway, Ahwaz, Iran, Tel. (0098) 61-35555557; email: behbahani@put.ac.ir*
[c]*Department of Petroleum Engineering, Petroleum University of Technology, Kut Abdollah, Near Imam Ali Square, Ahvaz-Abadan Expressway, Ahwaz, Iran, Tel. (0098) 61-35555557; Fax: (0098) 61-35556962; email: j.moghadasi@put.ac.ir*

Received 12 October 2015; Accepted 13 August 2016

ABSTRACT

Rag-e-Safid desalting unit No. 1 produces 3,126 barrels per day (bbl/d) of wastewater from oil processing in Rag-e-Safid oil field. This much wastewater, due to the high amount of minerals and total dissolved solids (TDS) is injected to disposal well – A through a 6-inch, 20-km pipeline. Injection of this wastewater into disposal well has had great damage and incurred high costs to Iranian oil company due to inorganic scales and corrosion damage in wastewater injection pipelines, wellhead and downwell equipment, the need for work over the well, and acidizing operations to remove scales. This article presents the predicting scale tendency and scale precipitation at different pressures, temperature, and mixing ratios of injection wastewater with formation water in disposal well – A of Iranian oil field. The experimentally measured chemical analyses of formation water and injection water were used by Scale Soft Pitzer software to determine the formation of these scales. This software has been applied to investigate the potential of scale formation in disposal wells of oil fields.

Keywords: Total dissolved solids; Disposal well; Rag-e-Safid desalting unit; Mixing ratio; Scale; Wastewater

1. Introduction

Scale is often defined as the precipitation from aqueous solution with inorganic sediments, and scale deposition is a problem commonly existing in different processes in oil field productions, for instance, water injecting, oil extracting, gathering and transporting, warming treatment, demulsification, crude oil dehydration and desalting, etc.; meanwhile, the scale is prone to be appeared on the downhole, oil well casing, oil pipelines, and other production equipments [1].

Formation water in underground reservoirs is in the vicinity of oil, and because of differences in density, it is underside the bed, and saturated water droplets are among oil molecules. Therefore, at the time of production of oil from the reservoir, water is one of the main partners of oil flow, which in addition to scaling of pipelines and equipment reduces the oil quality, and as far as possible, its amount should be reduced to the international standards for export or the standard of feed of refineries at wellhead separators and equipment at utilization and desalination plants. The injection of disposal water into oil field reservoirs to maintain reservoir pressure and improve secondary recovery is a well-established mature operation. Moreover, the degree of risk posed by deposition of inorganic scales to the injection and production wells during such operations has been much studied.

Scale formation in surface and subsurface oil and gas production equipment has been recognized as a major

---

* Corresponding author.

operational problem. It has also been recognized as a major cause of formation damage either in injection wells or in producing wells. Scale contributes to equipment wear and corrosion and flow restriction, thus resulting in a decrease in oil and gas production.

Experience in the oil industry has indicated that many oil wells have suffered flow restriction because of scale deposition within the oil producing formation matrix and the downhole equipment, generally in primary, secondary, and tertiary oil recovery operation as well as scale deposits in the surface production equipment.

There are other reasons why scale forms, and the amount and location of which are influenced by several factors. Supersaturation is the most important reason behind mineral precipitation.

A supersaturated condition is the primary cause of scale formation and occurs when a solution contains dissolved materials that are at higher concentrations than their equilibrium concentration. The degree of supersaturation, also known as the scaling index, is the driving force for the precipitation reaction, and a high supersaturation condition, therefore, implies higher possibilities for salt precipitation.

Scale can occur at/or downstream of any point in the production system at which supersaturation is generated. Scale can develop in the formation pores near the wellbore-reducing formation porosity and permeability. It can block flow by clogging perforations or forming a thick lining in production tubing. It can also coat and damage downhole completion equipment, such as safety valves and gas-lift mandrels [2]. Deposition of inorganic scales on rock surface can cause severe formation damage and may also trigger pore throat blockage or bridging. Scaling of safety valves can also be so serious making it impossible to close them in critical situations [3]. Supersaturation can be generated in single water by changing the pressure and temperature conditions or by mixing two incompatible waters. Changes in temperature, pressure, pH, and CO_2/H_2S partial pressure could also contribute to scale formation [4,5].

The purpose of this paper is to assess the potential for scale deposition in disposal well of Rag-e-Safid desalting unit No. 1 using Scale Soft Pitzer software. The paper will provide information about the possible causes of scale tendency of the wastewater in the disposal well of Rag-e-Safid desalting unit No. 1 and predicting scale formation in wastewater disposal well of Rag-e-Safid desalting unit No. 1.

2. Oil field scale types

The most common scales encountered in oil field operations are sulfates such as calcium sulfate (anhydrite, gypsum), barium sulfate (barite), and strontium sulfate (celestite) and calcium carbonate. Other less common scales have also been reported such as iron oxides, iron sulfides, and iron carbonate. Lead and zinc sulfide scale has recently become a concern in a number of North Sea gas and oil fields [6].

Therefore, the main types of scales are [7]:

- carbonates – mainly calcium carbonate, but also iron carbonate;
- sulfates – barium, strontium, and calcium;
- sulfide – less frequently encountered scales, but include lead, zinc, and iron; and
- salts – mainly sodium chloride.

Technically, these are scales, but are discussed.

2.1. Carbonates scale formation

Calcium carbonate or calcite and iron carbonate or siderite are frequently encountered in oil field operations. However, calcite has the greatest stability in oil field circumstances, so it is the most common form of calcium carbonate encountered in oil field production operation and disposal wells [8]. Deposition of $CaCO_3$ scale results from precipitation of calcium carbonate as per the following equation:

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3(S) + H_2O + CO_2(g) \tag{1}$$

Calcium carbonate scale can also be formed by a combination of calcium and bicarbonate ions, and this reaction is the major cause of calcium carbonate scale deposition in oil field operations. This is because only a small percentage of the bicarbonate ions dissociate at the pH values found in most injection waters to form H^+ and CO_3 [9].

Iron carbonate ($FeCO_3$) is one of the main corrosion products in the CO_2 corrosion process. Solid $FeCO_3$ forms on the steel surface if the product of ferrous ion concentration (Fe^{2+}) and carbonate ion concentration (CO_3^{2-}) exceeds the solubility product limit according to the reaction [10]:

$$Fe^{2+} + CO_3^{2-} \rightleftarrows FeCO_3 \tag{2}$$

The formation water in which the carbonate scale-forming components are initially dissolved becomes supersaturated with calcium carbonate due to the drop in pressure during production. The continuous flow of a supersaturated solution through the production equipment results in the growth of a dense layer of calcium carbonate crystals. Carbonate scales frequently appear in the wellbore, especially near the wellhead, where, due to the pressure drop, dissolved CO_2 escapes from produced water and causes the water pH as well as the saturation index of carbonate minerals to increase [8]. Another serious problem occurs when carbonate scales precipice from produced fluids containing acid gases. The deposition of carbonate can extend from the near wellbore matrix, along tubing and into surface equipment as the produced water continuously changes in pressure and temperature.

2.2. Sulfates scale formation

The chief source of oil field scale is mixing of incompatible waters. Two waters are called incompatible if they interact chemically and precipitate minerals when mixed. A typical example of incompatible waters are sea water with high concentration of SO_4^{2-} and low concentrations of Ca^{2+}, Ba^{2+}/Sr^{2+}, and formation waters with very low concentrations of SO_4^{2-} but high concentrations of Ca^{2+}, Ba^{2+}, and Sr^{2+}. Mixing of these waters, therefore, causes precipitation of $CaSO_4$, $BaSO_4$, and/or $SrSO_4$:

$$Ca^{2+}(\text{or } Ba^{2+} \text{or } Sr^{2+}) + SO_4^{2-} \rightleftarrows CaSO_4(BaSO_4 \text{or } SrSO_4) \tag{3}$$

Field produced water (disposal water) can also be incompatible with seawater. In cases where disposal water is mixed with seawater for re-injection, scale deposition is possible [11,12].

2.3. Sulfide scale formation

Metal sulfide scales, although less common than carbonate and sulfate scales, are still a hazard to some completions and reservoirs. Zinc and iron sulfide scales have all been reported, especially in high-temperature and high-salinity formations. Other fluid incompatibilities include sulfide scale where hydrogen sulfide gas mixes with iron and zinc rich formation waters:

$$Zn^{2+} + H_2S \rightleftarrows ZnS + 2H^+ \tag{4}$$

If a well has sour fluid (i.e., H_2S is present), a corrosion reaction is the most likely method for forming iron sulfide scale [13]. The net corrosion reaction is:

$$Fe + H_2S \rightleftarrows FeS + H_2 \tag{5}$$

Sulfate-reduction bacteria can be a source of hydrogen sulfide (H_2S), which then reacts with iron in solution or with steel surfaces to form iron sulfide [14].

2.4. Halite scale formation

Sodium chloride salt deposition is a type of scale that forms when the water becomes saturated with sodium chloride (halite). It is not a common problem, requiring highly saline brines or small quantities of water. It appears to be more common with gas wells, but has been reported on highly undersaturated oil reservoirs. Precipitation of sodium chloride (halite) is normally caused by supersaturation usually due to evaporation or decreases in temperature. Lower pressures also promote crystallisation, although this effect is slight unless temperatures are low [7].

3. Materials and methods

3.1. Study desalting unit

The Rag-e-Safid desalting unit No. 1 is located in Khuzestan province, approximately 6 km in nearest distance from the Persian Gulf, southwest Iran. This wastewater treating system consists of a skimmer tank, API gravity separator, filter, and disposal tank. Different crude oils bearing different formation waters are desalted in the Rag-e-Safid desalting No. 1 resulting in production of different wastewaters compositions. Rag-e-Safid desalting unit No. 1 makes 3,126 barrels per day (bbl/d) of wastewater from oil processing.

This high amount of wastewaters, due to the high amount of minerals and total dissolved solids (TDS), is injected to disposal well through a 6-inch, 20-km pipeline. When different wastewaters are mixed, it is necessary to evaluate their compatibility prior to the injection in the disposal well. One of the primary causes of scale formation and injection well plugging is mixing two or more wastewaters, which are incompatible. Rag-e-Safid oil field would be a good example of such field problem occurrence. This field consists of two main reservoirs, Rag-e-Safid Asmari and Rag-e-Safid Bangestan, and both of them produce wet crude.

These two wastewaters are mixed and injected into the disposal well – A in the depth of 2,774 m (9,101 ft). Well – A is an injection well that was considered to handle the disposal wastewater of Rag-e-Safid desalting unit No. 1. This well is completed in Asmari formation Rag-e-Safid field. The mixture of these two incompatible wastewaters has created enormous problems in the field.

The scale formation at the reservoir sandface has been resulting in a continuous decrease in the injection rate and eventually well plugging [15]. Injection of this wastewater disposal of Rag-e-Safid desalting unit No. 1 into disposal well has had great damage and incurred high costs to oil company due to mineral deposits and corrosion damage in wastewater injection pipelines, wellhead, and down-well equipment.

3.2. Sampling

To obtain an initial scale potential condition, the two samples of produced water of Rag-e-Safid desalting unit No. 1 and formation water of disposal well were sampled, and the influencing ions were analyzed and studied. Since the rate of the physical and chemical properties of water formation is continuously changing, the water sample is taken on 2 consecutive days, and then, the mean value of the two samples was presented according to Table 1. Before gathering water samples, each battery were washed three times with the same water sample and then filled with the sample of water formation. The packed samples were transferred into laboratory, and physical and chemical characteristics of water formation were analyzed over a period of 24 h.

Table 1
Complete water analysis of the disposal well – A and produced water from Rag-e-Safid desalting unit No. 1

Parameter	Rag-e-Safid desalting unit No. 1	Disposal well – A
Salinity, mg/L	76,284.901	245,434
Conductivity, µs/cm	113,454	361,617
Ionic strength, molal	1.55	6.16
pH	6	6.68
TDS, mg/L	72,515	231,733
Density, mg/L	1.0405	1.148
Sodium, mg/L	18,316.5	9,198
Potassium, mg/L	90	150
Magnesium, mg/L	3,640	9,720
Calcium, mg/L	3,926	60,000
Barium, mg/L	5.625	0
Iron, mg/L	1	633
Bicarbonate, mg/L	125	1,830
Chloride, mg/L	46,295	149,200
Sulfate, mg/L	112.5	1,000
Total alkalinity, mg/L as $CaCO_3$	102.459	1,500
CO_2 gas analysis, %	6.11	42.37

3.3. Analysis

Parameters are on-site measured such as pH, electrical conductivity (EC), and TDS. For the purpose of obtaining accurate results and avoiding the error, a specific device is calibrated and used in the measurements of these parameters. EC and TDS were measured with a Conductivity HACH apparatus. The hydrogen number (pH) was determined experimentally by device pH meter type (model pH A943TTT2).

The samples were analyzed for major components, Ca^{2+} and Mg^{2+} titration with 0.2 ethylenediaminetetraacetic acid (EDTA)–Na salt using Erich Chrome. Cations of formation water, Na^+, and K^+ were determined experimentally with flame photometer method (NIOSH-7300). Turbidimetric and argentometric methods were used for the determination of SO_4^{2-} and Cl^-, respectively, and the concentration of iron was determined using phenanthroline method [16]. The concentration of HCO_3^- and alkalinity was also measured by titration method with 0.02 N H_2SO_4. The concentration of cations and anions such as magnesium, strontium, barium, fluoride associated with formation water and produced water were determined using cations and anions of formation brine water and produced water were determined experimentally according to ASTM D4327 method [17]. Salinity value was calculated upon chloride content value. Density and specific gravity calculations were done using Scale Soft Pitzer software version 1. The experiments were performed at a temperature of 70°C, which is reasonable for Iranian oil fields. The mean of water analysis was represented in Table 1.

3.4. Use of the Scale Soft Pitzer software for scaling prediction

Scale Soft Pitzer™ is an Excel-based software program to predict scale formation for 6 different minerals (carbonates, sulfates, halite, sulfides, calcium fluoride, and silicates). This program is based upon the Pitzer theory of electrolytes, which is generally believed to be the best approach to calculate the effect of high T, P, TDS, composition on activity coefficients. The effect of hydrate inhibitors on mineral scale formation is included for calcite and barite. The effect of ten common scale inhibitors on nucleation kinetics, with or without hydrate inhibitors, is automatically calculated. Mixing of up to five brines and gases in any proportion and conditions is permitted. This program can be applied to oil field brines up to 300,000 mg/l in total dissolved salts (TDS), 350°F in temperature, and 14,000 psia in pressure. It has been tested extensively against booth experimental data in the literature and calculations from other speciation program.

There are several advantages over other commercially available scaling software:

- All reactions simulated in Scale Soft Pitzer™ software are pressure and temperature dependent.
- Accurately predicts the behavior of any mixture of chemicals in water and mixed solvent.
- The amount of CO_2 and H_2S automatically corrects at different temperatures and pressures.
- A data bank and recommendations for managing and remove inorganic scales.
- About 10 types of inhibitors consider the different conditions and use a variety of operating conditions deterrent to prevent scale formation and also prevent increased costs and reduced production.
- Scaling potential and scale buildup are reported at each calculation point.
- In this software, potential scale buildup can be found before it occurs, allowing preventive measures to be taken. This decreases production costs and lost production.
- The ability to calculate the mass of deposit at different temperatures and pressures as well bbl/d reports.

3.5. Scaling tendency prediction

In this module, the saturation index, SI, values are calculated based on the revised Oddo–Tomson SI algorithm. The scaling tendency of produced brine with respect to a scaling mineral is often expressed using the saturation index, defined as the logarithm of the lattice ion concentration product divided by the equilibrium constant. The relationship is:

$$\mathrm{SI} = \log \frac{[\mathrm{Me}][\mathrm{An}]}{\mathrm{K_{sp}}(\mathrm{P,T,I})} = \log\{[\mathrm{Me}][\mathrm{An}]\} - \log \mathrm{K_{sp}}(\mathrm{P,T,I}) \tag{6}$$

where Me = Mg^{2+}, Ca^{2+}, Sr^{2+} or Ba^{2+}, An = CO_3^{2-} or SO_4^{2-} and K_{sp} = solubility product.

The solubility product, Ksp is a thermodynamic quantity and is a function of temperature (*T*) and pressure (*P*) (although in most cases, the pressure functionality for solids can be ignored) and solution ionic compassion and solution ionic composition expressed as ionic strength (*I*).

When SI < 0, there is no potential for formation of scale; at 0, the water is saturated then the solution is at equilibrium with the solid scale; and where SI > 0, the water is oversaturated, and scale may form.

The change scale index (ΔSI) concept (2) is based on assumption that the brine is in equilibrium with carbonate (or sulfate) minerals present in reservoir rock, and thus a zero-SI exists with respect to that mineral under these conditions. Therefore, the ΔSI at a given location is the SI calibrated with the reference point (the reservoir condition). It is especially useful when analytical parameters are not complete or in doubt, because it reflects the changes in degree of supersaturation of the fluid in response to change in temperature and pressure. The ΔSI concept is the difference between the SI at the wellhead and the SI at the bottom-hole, which gives the range of supersaturation encountered in the production system [18]. Therefore, change scale index was defined as follows:

$$\Delta \mathrm{SI} = \mathrm{SI}_2 - \mathrm{SI}_1 \tag{7}$$

4. Results and discussion

This section deals with the results taken from running of the software for injection disposal water, formation water, and mixing of injection water with formation water of Rag-e-Safid oil field. Table 1 shows the analysis of the well – A water and produced water from Rag-e-Safid desalting unit No. 1.

4.1. Effect of pressure, mixing ratio, and temperature on $CaCO_3$ scale tendency and scale precipitation in disposal well – A

As you can see in Table 1, there are Ca^{2+} and HCO_3^- ions exist in well – A, which cause the possibility of $CaCO_3$ scale formation. The amount of this scale is predicted by Scale Soft Pitzer software and plotted in Fig. 1 for different pressures in well – A. As can be seen in this figure, the amount of SI and ΔSI $CaCO_3$ precipitation is greater than zero, and therefore, the $CaCO_3$ scale will be formed in well – A. According to Fig. 1, by increasing pressure from the surface to the bottom of reservoir, changes in SI and ΔSI have a downtrend.

Also, the amount mass of this scale formation plotted in Fig. 2 for different pressures in well – A. This figure shows that calcium carbonate scale deposition increases with decreases of pressure. Pressure drop increases CO_2 gas partial pressure and increases the scale deposition of calcium carbonate. Pressure drop reduces the amount of CO_2 dissolved in the water and hence causes a progressive increase in supersaturation with respect to calcium carbonate. This will result in increasing scale deposition from calcium carbonate [19].

Fig. 3 illustrates the results of $CaCO_3$ scale tendency at different mixing ratios of injection water with formation water for well – A. In well – A, when percentage of injection water is increased, then the $CaCO_3$ scale tendency is decreased.

The amount of $CaCO_3$ scale tendency in the wellhead is greater than that of the bottom-hole, because of drop pressure and temperature, and the presence of Ca^{2+} ion exists in the surface and the wastewater injection to disposal well – A.

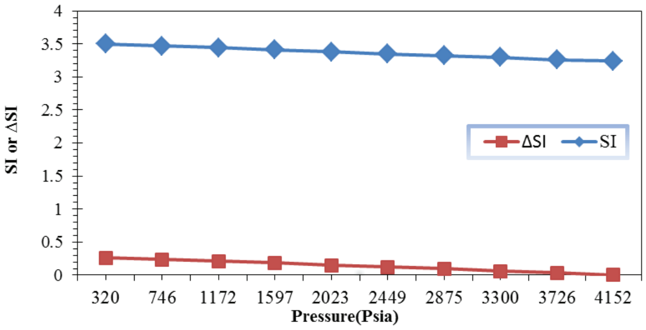

Fig. 1. SI and ΔSI changes for $CaCO_3$ (calcite) scale tendency in well – A (injection water: Rag-e-Safid desalting unit No. 1).

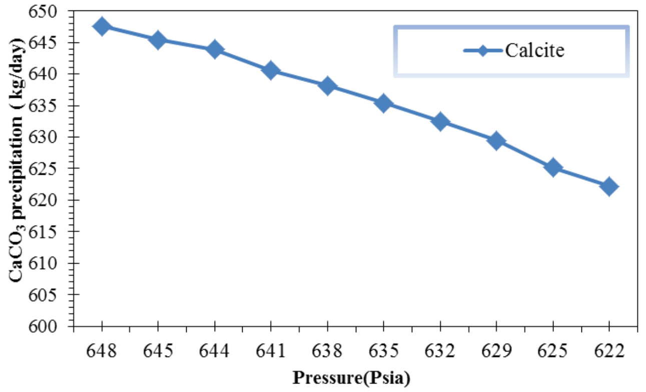

Fig. 2. Prediction of $CaCO_3$ (calcite) precipitation in well – A (injection water: Rag-e-Safid desalting unit No. 1).

Solubility of $CaCO_3$ is greatly influenced by the carbon dioxide content of the water, and temperature increases. $CaCO_3$ becomes less soluble as temperature increases. During heating, CO_2 comes out of solution and precipitation of calcium carbonate. Supersaturation was the most important reason behind mineral precipitation. Increased supersaturation would result in a more rapid rate of scale precipitation. Fig. 4 shows the effect of temperature on $CaCO_3$ scale precipitation different mixing ratios of injection water with formation water for disposal well – A. This figure shows that calcium carbonate scale deposition increases with temperature.

4.2. Effect of pressure and temperature on types of sulfate scale tendency in disposal well – A

As you can see in Table 1, there are Ca^{2+} (60,000 mg/l), and SO_4^{2-} (1,000 mg/l) ions exist in well – A, which cause the possibility of $CaSO_4$ scale formation. The amount of this scale is predicted by Scale Soft Pitzer software and plotted in Fig. 5 for different pressures in well – A. As can be seen in Fig. 5, the amount of SI gypsum ($CaSO_4.2H_2O$) precipitation is greater than zero, and therefore, the $CaSO_4.2H_2O$ scale will

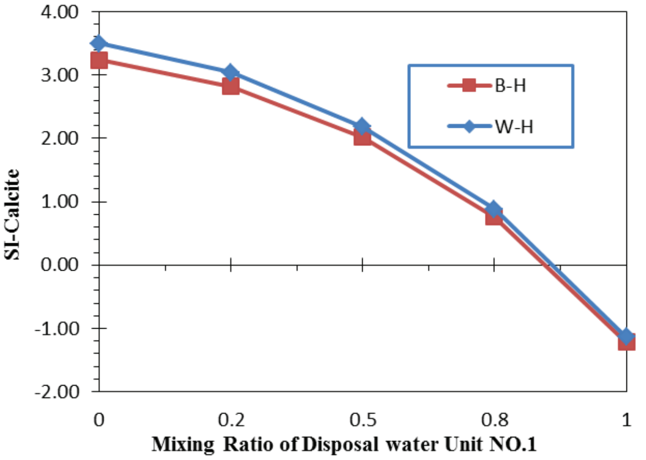

Fig. 3. Prediction of $CaCO_3$ (calcite) scale tendency at different mixing ratios of injection water with formation water in well – A.

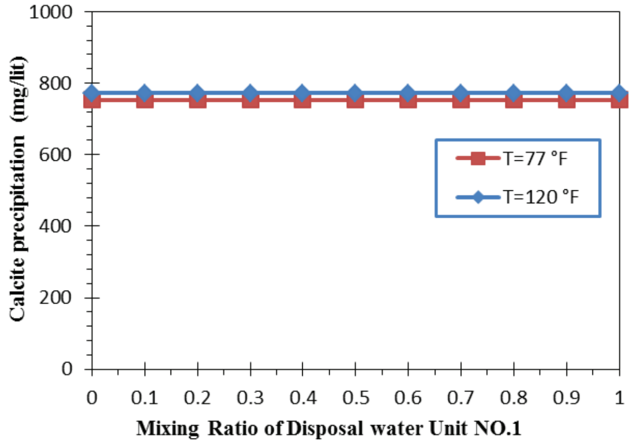

Fig. 4. Prediction of $CaCO_3$ (calcite) scale tendency at different temperatures of injection water with formation water in well – A.

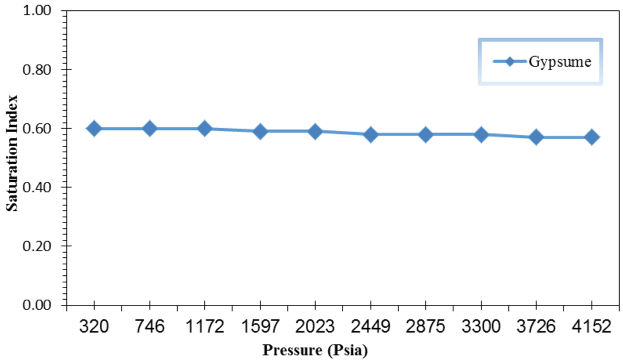

Fig. 5. SI changes for $CaSO_4.2H_2O$ (gypsum) scale tendency in well – A (injection water: Rag-e-Safid desalting unit No. 1).

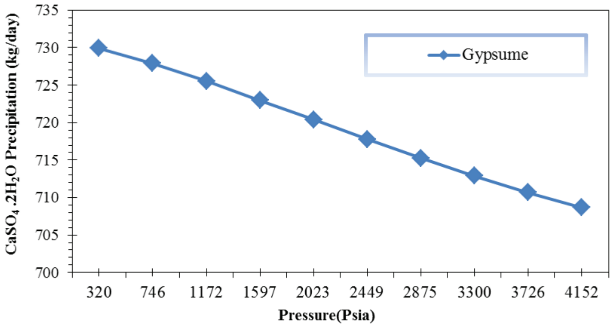

Fig. 6. Prediction of $CaSO_4.2H_2O$ (gypsum) precipitation in well – A (injection water: Rag-e-Safid desalting unit No. 1).

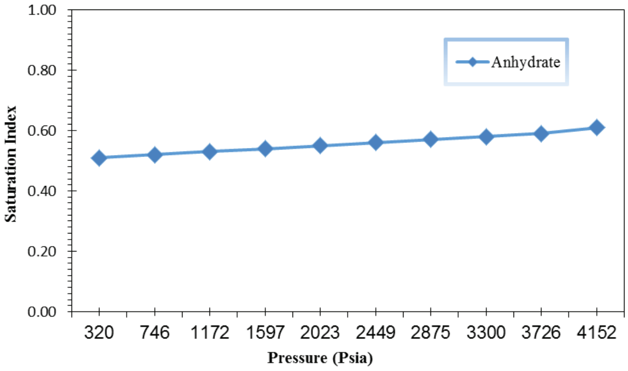

Fig. 7. SI changes for $CaSO_4$ (anhydrate) scale tendency in well – A (injection water: Rag-e-Safid desalting unit No. 1).

be formed in well – A. Also, the amount mass of this scale formation plotted in Fig. 6 for different pressures in well – A. This figure shows that gypsum scale deposition increases with decreases temperature.

Figs. 7 and 8 illustrate the result of compatibility modeling for wastewater injection into the disposal well – A. It can be seen that anhydrate ($CaSO_4$) scale is the likely type of scale to be formed under the modeling conditions, for this case.

The amount of this scale is predicted by Scale Soft Pitzer software and plotted in Fig. 7 for different pressures in well – A. As can be seen in this figure, the amount of SI anhydrate ($CaSO_4$) precipitation is greater than zero, and therefore, the anhydrate ($CaSO_4$) scale will be formed in well – A. Also, the amount mass of this scale formation plotted in Fig. 8 for different pressures in well – A. This figure shows that anhydrate scale deposition increases with decreases of pressure. Pressure drop reduces the solubility of calcium sulfate and increases the scale deposition of calcium sulfate.

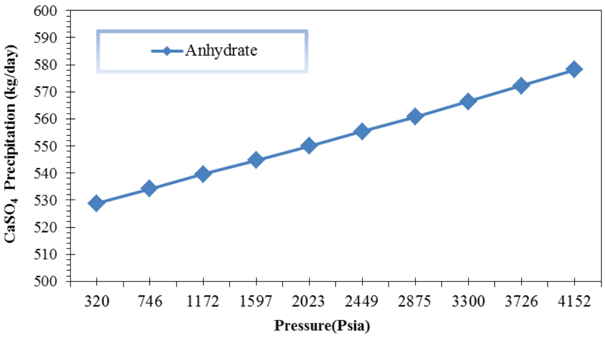

Fig. 8. Prediction of $CaSO_4$ (anhydrate) precipitation in well – A (injection water: Rag-e-Safid desalting unit No. 1).

Temperature has a significant influence on solubility and crystal growth of calcium sulfate. Figs. 9 and 10 show the effect of temperature on a scale tendency at different mixing ratios of disposal water desalting unit No. 1 with formation water for disposal well – A. These figures show that calcium sulfates scales deposition increases with temperature. The increase in temperature also causes a rise in supersaturation, because the solubility of $CaSO_4$ decreases with temperature. This must have led to an increase of rate of precipitation.

4.3. Effect of pressure and temperature on $FeCO_3$ scale tendency and scale precipitation in disposal well – A

As can be seen in Table 1, there exist some Fe^+ and HCO_3^- ions in formation water and injection water of the well – A, which cause the possibility of $FeCO_3$ scale formation. The amount of this scale is predicted by Scale Soft Pitzer software and plotted in Fig. 11 for different pressures in well – A. As can be seen in this figure, the amount of saturation index (SI) and ΔSI $FeCO_3$ precipitation is greater than zero, and therefore, the $FeCO_3$ scale will be formed in well – A. According to Fig. 11, by increasing pressure from the surface to the bottom of well, changes in SI and ΔSI have a downtrend.

Also, the amount mass of this scale formation plotted in Fig. 12 for different pressures in well – A. This figure shows that iron carbonate scale deposition increases with decreases of pressure. Pressure drop increases of CO_2 gas partial pressure and increases the scale deposition of iron carbonate.

Solubility of $FeCO_3$ is greatly influenced by the carbon dioxide content of the water and temperature increases. Supersaturation was the most important reason behind mineral precipitation. Increased supersaturation would result in a more rapid rate of scale precipitation. Fig. 13 shows the effect of temperature on $FeCO_3$ scale tendency at different mixing ratios of two different waters. This figure shows that iron carbonate scale deposition increases with temperature. $FeCO_3$ becomes less soluble as temperature increases. During heating, CO_2 comes out of solution and precipitation of iron carbonate.

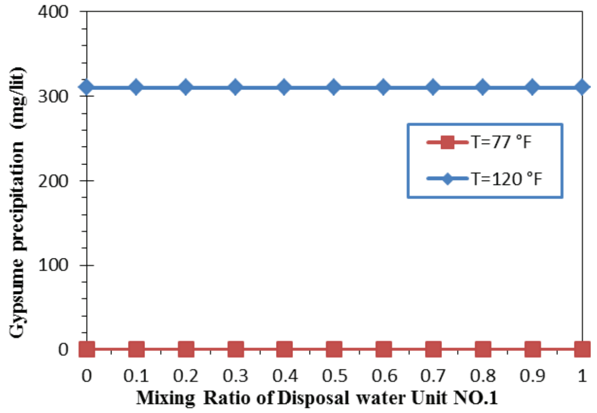

Fig. 9. Prediction of $CaSO_4.2H_2O$ (gypsum) scale tendency at different temperatures of injection water with formation water in well – A.

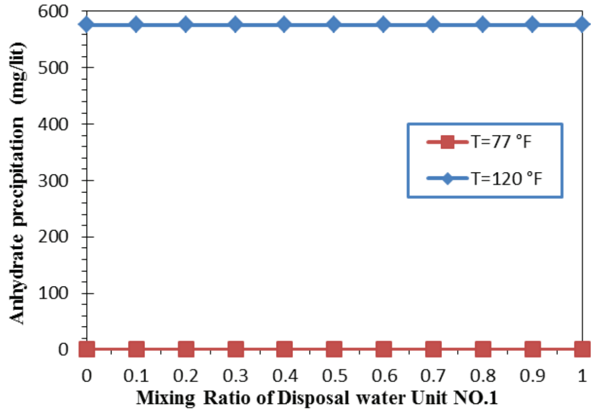

Fig. 10. Prediction of $CaSO_4$ (anhydrate) scale tendency at different temperatures of injection water with formation water in well – A.

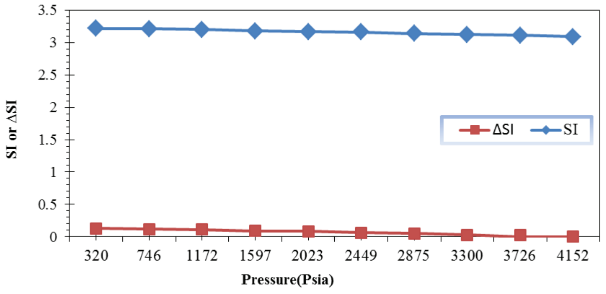

Fig. 11. SI and ΔSI changes for $FeCO_3$ (iron carbonate) scale tendency in well – A (injection water: Rag-e-Safid desalting unit No. 1).

5. Conclusions

From the overview of scale prediction within the wastewater disposal well of Rag-e-Safid desalting unit No. 1, there are some significant results and conclusions as follows:

- This program is accurate, simple, and easy to use and will find many applications in oil and gas productions.

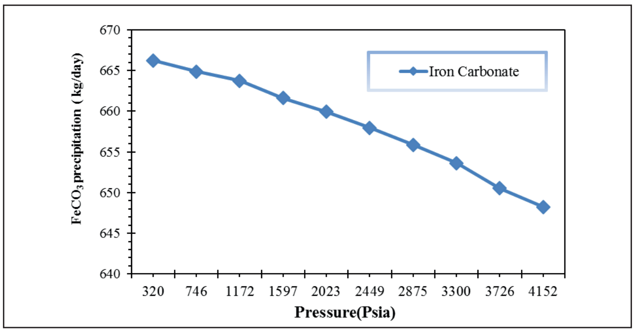

Fig. 12. Prediction of $FeCO_3$ (iron carbonate) precipitation in well – A (injection water: Rag-e-Safid desalting unit No. 1).

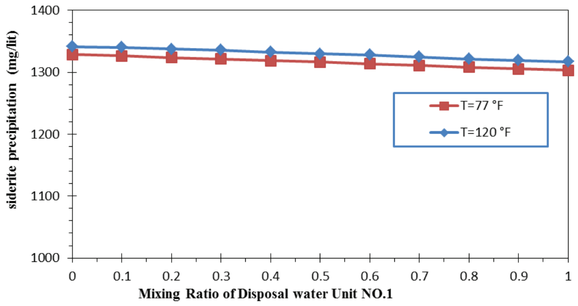

Fig. 13. Prediction of $FeCO_3$ (siderite) scale tendency at different temperatures of injection water with formation water in well – A.

- This model calculates the precipitation of scale forming compounds under all pertinent wastewater disposal well conditions.
- Graphics improve interpretation and results in better decisions. Graphics also help communicate information to others.
- Figures show that the calcium carbonate, iron carbonate, and calcium sulfates scales deposition increases by a pressure drop. Pressure drop increases of CO_2 gas partial pressure and increases the scale deposition of calcium and iron carbonate.
- Several factors influencing scale formation had been examined. Concentration of brine (i.e., supersaturation), mixing ratio of the injection water with formation water and increasing pressure, had a detrimental effect on the scale deposition and permeability reduction.
- To predict the various aspects of scale formation in disposal wells and to improve the chances of controlling it, in-depth integrated chemical modeling and laboratory tests are necessary.
- Formation of $CaCO_3$ and $FeCO_3$ is very high; therefore, it is suggested to use hydrochloric acid for dissolving this scale.
- The main influencing factors on scale formation have been examined. Temperature change had a remarkable effect on the scaling rate. At higher temperatures, calcium sulfate deposition is increased because the solubility of $CaCO_3$, $CaSO_4$, and $FeCO_3$ decreases with increasing temperature. This must have increased the rate of precipitation, and consequently, the permeability declines.

- The strong incompatibility between formation water and wastewater disposal results in the prediction of severe problems of $CaCO_3$, $CaSO_4$, and $FeCO_3$ scaling in the disposal wells.
- Water sampling must be done at least every 2 months, but for critical disposal wells the frequency should be weekly. Well model of scale must be updated frequently according to the new samples.
- Increase of $CaCO_3$ and $FeCO_3$ deposition due to acidizing of disposal well is more than the other scenarios because corrosion rate increases more for this scenario. When high amounts of iron in the form of Fe^{3+} (ferric ions), rather than the usual Fe^{2+} (ferrous ions), are dissolved by the acid, $FeCO_3$ scale deposition can occur after acidizing. Iron ions may result from the dissolution of rust in the tubing, casing, or metals facilities by the acid solution in disposal wells.
- Figures illustrate the predicted scale deposition due to mixing of two different water of the disposal well – A and produced water from Rag-e-Safid desalting unit No. 1. In all cases, $CaCO_3$, $CaSO_4$, and $FeCO_3$ scale may be expected for disposal well of Rag-e-Safid desalting unit No. 1. The amount of scale tendency in the wellhead is greater of the bottom-hole, because of drop pressure and temperature, and the presence of concentrations of cations with desalting unit water exists in the surface and the wastewater injection to disposal well – A.

Acknowledgment

The authors wish to thank the Energy & Environmental Systems Institute Rice University for allowing them to work with the Scale Soft Pitzer software. The support of National Iranian South Oil Company (NISOC) for providing research facilities is also acknowledged.

Symbols

An — Anion
K_{sp} — Solubility product, M^2
Me — Metal
P — Pressure, psi
T — Temperature, °F
SI — Scaling index or saturation index, dimensionless
ΔSI — Delta scaling index, dimensionless
TDS — Total dissolved solid, mg/L
B-H — Bottom-hole
W-H — Wellhead

References

[1] H. Luo, D. Chen, X. Yang, X. Zhao, H. Feng, M. Li, J. Wang, Synthesis and performance of a polymeric scale inhibitor for oilfield application, J. Pet. Explor. Prod. Technol., 5 (2015) 177–187.

[2] M. Crabtree, D. Eslinger, P. Fletcher, A. Johnson, G. King, Fighting Scale: Removal and Prevention, Schlumberger Oilfield Review, 1999, pp. 30–45.

[3] H. Safari, M. Jamialahmadi, Thermodynamics, kinetics, and hydrodynamics of mixed salt precipitation in porous media: model development and parameter estimation, Transp. Porous Media, 101 (2014) 477–505.

[4] J.E. Mackay, Modeling *in-situ* scale deposition: the impact of reservoir and well geometries and kinetic reaction rates, SPE Prod. Facil., 18 (2003) 45–56.

[5] J. Moghadasi, M. Jamialahmadi, H. Muller-Steinhagen, A. Sharif, A. Ghalambor, R.M. Izadpanah, E. Motaie, Scale Formation in Iranian Oil Reservoir and Production Equipment during Water Injection, Paper No. SPE 80406, Presentation at the International Symposium on Oilfield Scale, Aberdeen, UK, 2003, pp. 1–14.

[6] R.I. Collins, M.M. Jordan, Occurrence, Prediction and Prevention of Zinc Sulfide Scale within Gulf Coast and North Sea High Temperature/High Salinity Production Wells, Paper No. SPE 68317, SPE Third International Symposium on Oilfield Scale, Aberdeen, UK, 2001, pp. 1–17.

[7] J. Bellarby, Well Completion Design, NACE International and TRACS International Consultancy Ltd., 1st ed., Elsevier, Aberdeen, UK, 2009, pp. 374–394.

[8] M. Amiri, J. Moghadasi, The effect of temperature on calcium carbonate scale formation in Iranian oil reservoirs using OLI ScaleChem software, Pet. Sci. Technol., 30 (2012) 453–466.

[9] J. Moghadasi, M. Jamialahmadi, H. Muller-Steinhagen, A. Sharif, Formation Damage due to Scale Formation in Porous Media Resulting from Water Injection, Paper No. SPE 86524, SPE International Symposium and Exhibition on Formation Damage Control, Lafayette, LA, 2004, pp. 1–11.

[10] M. Amiri, J. Moghadasi, M. Jamialahmadi, Prediction of iron carbonate scale formation in Iranian oilfields at different mixing ratio of injection water with formation water, Energy Sources Part A, 35 (2013) 1256–1265.

[11] M. Amiri, J. Moghadasi, M. Jamialahmadi, A prediction of the amount of strontium sulfate scale formation in Siri oilfield at different temperatures and pressures, Energy Sources Part A, 36 (2014) 14–15.

[12] A.B. Bin Merdhah, The Study of Scale Formation in Oil Reservoir during Water Injection at High-barium and High-salinity Formation Water, M.Sc. Thesis, Universiti Teknologi Malaysia, 2007.

[13] W. Frenier, M. Ziauddin, Formation, Removal, and Inhibition of Organic Scale in the Oilfield Environment, Society of Petroleum Engineers, 2008, pp. 38–39.

[14] T.O. Allen, A.P. Roberts, Prediction Operations, Well Completions, Workover and Stimulation, Vol. 2, OGCI and PetroSkills Publications, Tulsa, Oklahoma, 1989, pp. 248–249.

[15] A. Bahadori, K. Zeidani, Predicting scale formation in wastewater disposal wells of crude-oil desalting plants, Pet. Coal, 54 (2012) 143–148.

[16] E.W. Rice, L. Bridgewater, Standard Methods for the Examination of Water and Wastewater, 20th ed., APHA/AWWA/WEF, Washington, DC, 2012.

[17] Annual Book of American Standard Test Method, ASTM-D4327-91, Vol. 11.01, 1992, pp. 336–337.

[18] S.L. He, M.B. Kan, A.T. Tomson, J.E. Oddo, A New Interactive Software for Scale Prediction, Control, and Management, Paper No. SPE 38801, SPE Annual Technical Conference and Exhibition, San Antonio, Texas, USA, 1997.

[19] J. Moghadasi, H. Müller-Steinhagen, M. Jamialahmadi, A. Sharif, Prediction of Scale Formation Problems in Oil Reservoirs and Production Equipment due to Injection of Incompatible Waters, Produced Water Management in Oil and Gas International Conference, Cairo, Egypt, Vol. 14, 2006, pp. 25–28.