2011 International Conference on Environment and BioScience
IPCBEE vol.21 (2011) © (2011) IACSIT Press, Singapore

A Reliable approach for Barite, Celestite and Gypsum scaling propensity prediction during reverse osmosis treatment for produced water

Emad Alhseinat[1+], Roya Sheikholeslami[1]

[1] The University of Edinburgh, EH9 3JL

Abstract. Reverse osmosis desalination is considered a promising solution for Produced Water problem in oil and gas industry. In fact, desalination of Produced Water may transfer Produced Water from a grave problem that burdens the oil and gas industry to a useful commodity used as part of a solution to the problem of fresh water shortage. However, Scaling problem is one of the main challenges that face Produced Water desalination. Actually, Scaling limits the economic viability of Produced Water desalination. Thus, scaling mitigation is very crucial and must be considered in any attempt for Produced Water desalination. The first step in scaling mitigation is to predict the scaling propensity of the feed water. Unfortunately, there is an immense shortage in the current industrial practice for determination of scaling propensity. This shortage comes from using old and inapplicable approaches where crucial assumptions are made to simplify these predictions; these old approaches were suitable for the era that the computer access was limited and also not generally applied in water industry. This paper uses the theoretical Scaling Potential Index (SPI) proposed by (Sheikholeslami 2005) and previously used in reverse osmosis set up (R.Sheikholeslami, Y.Wang et al. 2011; Sheikholeslami 2011) incorporates the use of Pitzer ion interactive forces previous proposed for seawater desalination (Sheikholeslami and Ong 2003) and combining them with the principles of mass transfer and membrane transport used by (Song, Hong et al. 2002) along the membrane module to predict the scaling propensity along the membrane module. This approach considers the interactive effect resulted from precipitation salts and non precipitation salts co-existence as recommended previously (Sheikholeslami and Ong 2003). And moreover it considers the substantial change in salts concentrations and system variables and parameters within a full-scale RO. As a result, a reliable prediction of the scaling propensity in full scale reveres osmosis process is made. In this paper scaling propensity of barite, celestite and gypsum, as a major scaling salts in Produced Water, have been assessed and discussed. Moreover, the effect of applied pressure, initial cross flow velocity and feed salinity on scaling propensity of barite, celestite and gypsum have been examined and discussed.

Keywords: Reverse Osmosis, Produced Water Desalination, Scaling, Scaling Propensity, Barite, Celestite.

1. Introduction

Produced Water is the wastewater produced during hydrocarbon (such as oil, gas and tar sand) processing. The following four reasons make the desalination of Produced Water attractive for the oil and gas industry: Firstly, the huge amount of globally Produce Water is estimated at around 250 million barrels/day compared with around 80 million barrels/day of oil (Fakhru'l-Razi, Pendashteh et al. 2009). The amount of Produced Water makes it the largest waste stream by volume associated with the oil and gas industry and makes the disposal of it a grave problem and burdens the oil and gas industry. Secondly, the high overall cost of the Produced Water disposal as a result of increasing in disposal regulatory constraints for environmental concerns makes the economics unpalatable. Thirdly, the fresh water shortage especially in the region, like gulf reign, where most oil and gas produced countries are located makes the desalination of Produced Water beneficial which could potentially help to reduce the problem of fresh water scarcity.

[+] Corresponding author. Tel.: + (441316508564);
E-mail address: (e.alhseinat@ed.ac.uk).

Fourthly, the results of recent research studies by BP show that injection of desalted water to the oil well has a significant positive impact on the oil recovery (McGuire, Chatham et al. 2005).

However, scale formation seems to be a limiting factor in the desalination of Produced Water. Scaling limits the economic viability of Produced Water desalination by increasing the energy consumption and decreasing the efficiency of the process. Therefore, scaling mitigation is crucial for applying the desalination technology to the Produced Water. The first step on scaling mitigation is the prediction of the scaling propensity for specific feed water. The current practice for assessing the scaling propensity are based on empirical relationships that are not suitable for membrane processes (Sheikholeslami 2004), the empirical indices used for assessment the potential of precipitation fouling which is commonly referred to as scaling have been discussed in detail elsewhere (Sheikholeslami 2005). In fact the complex characteristics of Produced Water exacerbate the problem of scaling because of the high probability of scaling when salts such as $CaCO_3$, $CaSO_4$, $BaSO_4$ and $SrSO_4$ co-exist. Since, the mechanism of fouling is expected to be different for different salts as it was demonstrated for $CaCO_3$ and $CaSO_4$ (Bansal.B, Müller-Steinhagen.H et al. 1997). And moreover, (Sheikholeslami 2007) and her research group show that the co-existence of precipitating salt affects the mechanism of fouling, the thermodynamic, and kinetic behavior of each salt; hence, the single salt data is not applicable to the situation where salts co-exist. So the application of the current industrial practice for assessing the scaling propensity in desalination plant is limited and only maybe able to approximate the scaling propensity for simple feed water at the entrance to the RO desalination unit. Moreover, any effort for scaling propensity prediction must consider the substantial change on system variables and parameters during full scale desalination process. So the current practice make their prediction unrealistic for describing full-scale RO process that along membrane channel, where system variable and parameters change substantially along the long membrane channel (Chen, Song et al. 2004).

Therefore, this paper comes to apply a new reliable approach based on combining Sheikholeslami's SPI (Sheikholeslami 2005) to predict the scaling propensity of Produced Water in full scale RO desalination. This reliable approach has been used to study the effect of operation variables such as applied pressure and feed salinity on scaling propensity development for the major scaling salts that could be faced during Produced Water desalination

2. Model Development

To predict scaling development along a membrane channel there is need firstly to describe the change on scaling ions and non-scaling ions concentration along the membrane filtration channel. Simulating the ions behavior and interactive forces of Pitzer as previously used (Sheikholeslami and Ong 2003) concentrating along the membrane channel could be used to determine the interactive effects for the long and short interactive forces. Simulating the behavior of the ions concentration along the membrane channel could be reached through using the principles of membrane transport and mass conservation used by (Song, Hong et al. 2002) to predict the variations of variables and parameters in a long membrane channel. Moreover, using this fundamental principle; the effect of operating parameters such as feed flow rate and the applied pressure on scaling propensity development could be examined and verified. And furthermore, in case of scaling it could extend the theoretical Scaling Potential Index (SPI) developed by (Sheikholeslami 2005; R.Sheikholeslami, Y.Wang et al. 2011; Sheikholeslami 2011) which depends on Gibbes free Energy to find the scaling propensity of all the scaling salt along the membrane filtration channel.

3. Simulation for scaling propensity in full-scale RO

Numerical simulations have been conducted to investigate the effect of operating variables on scaling propensity development along a full-scale RO process. In order to clarify scaling propensity development inside practical RO systems, the parameter values used in these simulations were either chosen from the manufacturers' specifications or practical operating conditions as followed by (Song, Hong et al. 2002). This simulation is capable to predict the effects of the variations of operation variables and parameters along membrane channel on the development of scaling tendency. Unless otherwise specified, Table 1 shows the values of the parameters that have been used in this simulation as well as that of (Song, Hong et al. 2002).

Table1. Parameter values for model Simulations

Length of RO system, L (m)	6
Channel height, H (m)	7 x 10^{-4}
Applied (pump) pressure, p_0 (Pa)	5.516 x 10^6
Feed Salinity (mg/l)	30000
Cross flow velocity at entrance,(m/s)	0.1
Membrane intrinsic resistance,(Pa s/m)	1.8 x 10^{11}
Number of elements along RO system	400
Temperature, °C	25
Initial Ca^{2+} concentration, ppm	1500
Initial SO_4^{2-}, ppm	2000
Initial Ba^{2+}, ppm	0.02
Initial Sr^{2+}, ppm	20

3.1. Scaling propensity for $BaSO_4$, $SrSO_4$ and $CaSO_4$ along 6 m membrane channel.

Scaling potential index gives a conservative estimate for assessing scaling potential; when *SPI* is negative, certainly no scale will form; when zero the system is at equilibrium; when the *SPI* is positive, the salt has a "potential" to form scale (Sheikholeslami, 2005). Figure 1 shows the development of scaling propensity for barite, celestite and gypsum in terms of *SPI*, it is seen that at this particular simulation conditions the *SPI* for barite, celestite and gypsum were below zero for the first meter along the permeation channel which means that in this section of the membrane there will not be any scale formation. However, an increase in scaling propensity of barite and gypsum develops afterwards which reaches the maximum approximately at about 3m along the channel. Moreover, it is seen that the celestite precipitation could start to occur towards the last half of the membrane channel, where it is expected to have barite and gypsum scales as well.

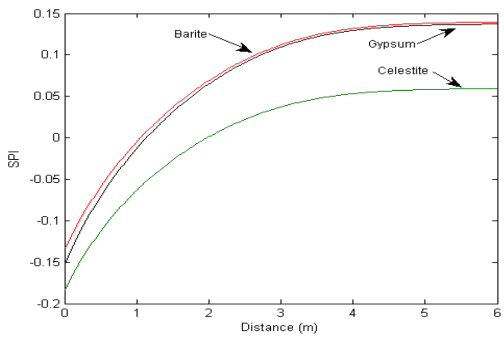

Fig.1. Scaling propensity development for Barite, Celestite and Gypsum precipitation.

These observations demonstrate that it is expected to have severe scaling after 3m of the membrane channel - *SPI* for all the species increases along the length as a result of increases in the concentration of the scaling salts along the concentrate channel.

3.2. Effect of initial cross flow velocity on scaling propensity development for Barite, Celestite and Gypsum.

Figure 2 shows the effect of various initial cross flow velocities on scaling propensity of barite, celestite and gypsum precipitation development along 6m RO channel. It is shown that cross flow velocity has very important impact on scaling propensity development. The same trends are observed for the three scales (barite, celestite and gypsum) confirming that the lowest cross flow velocity results in the highest scaling propensity. Thus, cross flow velocity should be optimized to reduce scaling propensity for all scaling salts. Therefore, this simulation could be used to have optimum cross flow velocity.

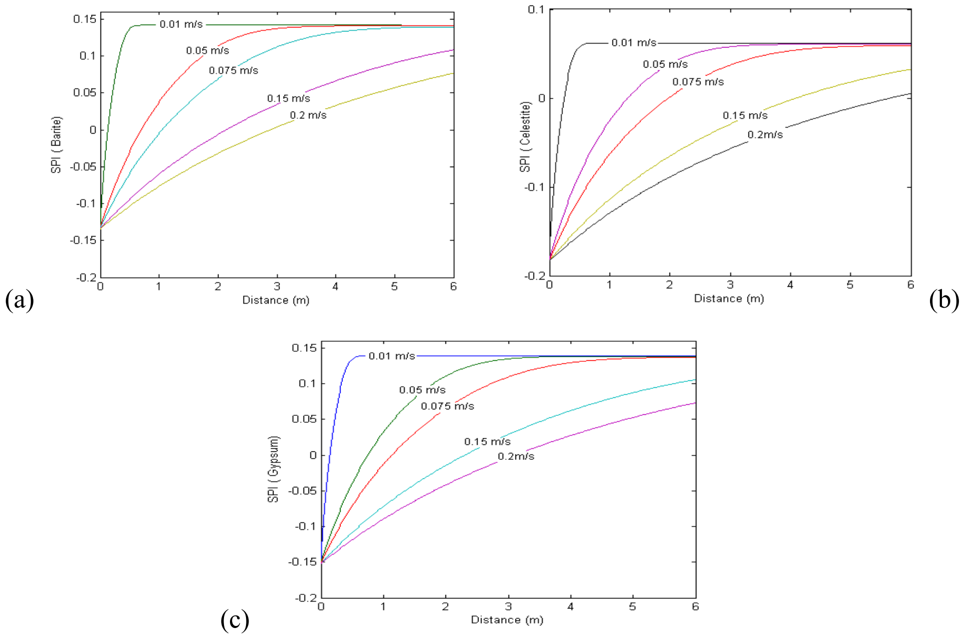

Fig.2. Effect of initial cross flow velocity on scaling propensity development for (a) Barite precipitation (b) Celestite precipitation (c) Gypsum precipitation.

As seen from the above figure operating the RO at 0.2 m/s cross flow velocity will help to avoid celestite scaling and minimize barite and gypsum scaling.

3.3. Effect of applied pump pressure on scaling propensity development for Barite, Celestite and Gypsum

The applied pressure is one of the operating variables that affect the scaling propensity. Figure 3 shows the development of scaling propensity of barite, celestite and gypsum for different values of applied pressure. It is shown that increasing applied pressure leads to change in the development of scaling propensity. As seen at highest applied pressure the membrane is more prone to scale formation. Thus, the theoretical *SPI* enables one to operate within the safe operational limit. For example according to figure 3 operating the RO at 45 bar will certainly avoid precipitating of celestite and minimize the barite and gypsum scaling.

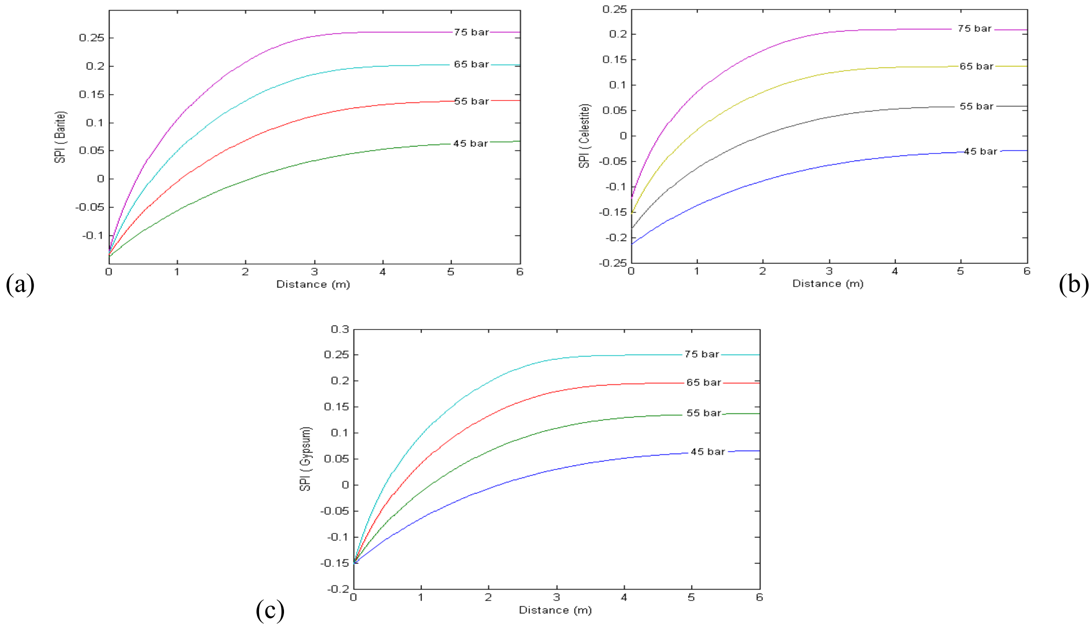

Fig. 3. Effect initial applied pressure on scaling propensity prediction for (a) Barite precipitation (b) Celestite precipitation (c) Gypsum precipitation.

3.4. Effect of initial feed water salinity on Scaling propensity development for Barite, Celestite and Gypsum.

Salinity of feed water to RO process varies from location to location and may vary with time at a given location as well. Therefore, Figure 4 has been plotted to show the effect of salinity variation on scaling propensity of barite, celestite and gypsum in term of *SPI*. It is noted from Figure 4 that at higher feed water salinities, with other parameters constant, the lower would be for scaling propensity along the membrane channel. Also it seen from figure 4(b) that at salinity 30000ppm will be no celestite scaling since the *SPI* curve is negative along the channel. The decrease in scaling propensity development along the permeation channel as the salinity of feed water increase is due to the effect of salinity on the driving force ($\Delta P\text{-}\alpha C_i$) for the permeate flux as well on the ion activity. Therefore, as the salinity increases the net driving force decreases and the permeate flux will decrease leading to decrease in ions concentration and scaling development.

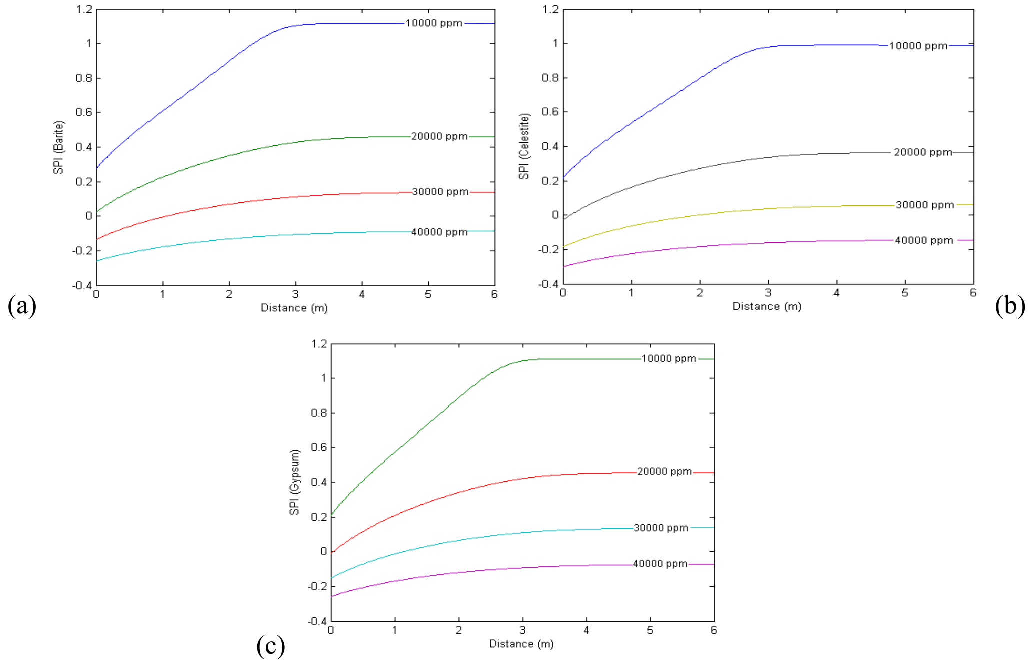

Fig.4. Effect of feed salinity on scaling propensity prediction for (a) Barite precipitation (b) Celestite precipitation (c) Gypsum precipitation.

Another reason for the decrease in scaling propensity as a result of increase in feed salinity is the increase in solubility limit due to the increase of non-precipitating salt (NaCl) concentration which increases the ionic strength of the solution thus increasing the interaction between the two precipitating species that elevate the solubility limit (Sheikholeslami and Ong 2003).

4. CONCLUSION

This paper uses fundamental relationships to reliably simulate and assess scaling propensity of barite, celestite and gypsum, as a major scaling salts face in produced water desalination, along full-scale RO membrane. This reliable simulation has been reached through incorporation of the localized parameters along the membrane filtration channel in a fundamental and unified approach for assessing the scaling potential. This approach enables us to study the effect of hydrodynamic and interactive effects on scaling potential from the fundamental principles. The effects of initial applied pressure, initial cross flow velocity, initial feed water salinity and feed water temperature on scaling propensity development of barite, celestite and gypsum were investigated and discussed. The ability to simulate the operational conditions and performance is important for operating the RO unit within the most suitable operational limit to avoid scaling.

5. RFERENCES

[1] Bansal.B, Müller-Steinhagen.H, et al. (1997). "Effect of Suspended Particles on Crystallization Fouling in Plate Heat Exchangers." TRANSACTIONS- AMERICAN SOCIETY OF MECHANICAL ENGINEERS JOURNAL

OF HEAT TRANSFER **119**(3): 568-574

[2] Chen, K. L., L. Song, et al. (2004). "The development of membrane fouling in full-scale RO processes." Journal of Membrane Science **232**(1-2): 63-72.

[3] Fakhru'l-Razi, A., A. Pendashteh, et al. (2009). "Review of technologies for oil and gas produced water treatment." Journal of Hazardous Materials **170**(2-3): 530-551.

[4] McGuire, P. L., J. R. Chatham, et al. (2005). Low Salinity Oil Recovery: An Exciting New EOR Opportunity for Alaska's North Slope. SPE Western Regional Meeting.

[5] R.Sheikholeslami, Y.Wang, et al. (2011). Application of Theoretical Scaling Potential Index to Predict Onset of Composite Calcium Carbonate and Calcium Sulfate Fouling and Crystal Types and Phases in Seawater Revese Osmosis Treatment. Water Production and Wastwater Treatment. B.Antizar-Ladislao and R.Sheikholeslami, Nova Publsher**:** 269-284.

[6] Sheikholeslami, R. (2004). "Assessment of the scaling potential for sparingly soluble salts in RO and NF units." Desalination **167**: 247-256.

[7] Sheikholeslami, R. (2005). "Scaling potential index (SPI) for CaCO3 based on Gibbs free energies." AIChE Journal **51**(6): 1782-1789.

[8] Sheikholeslami, R. (2007). Fouling in Membranes and thermal Units: A Unified Approach- Its Principles, Assessment, Control and Mitigation, Balaban Desalination Publications.

[9] Sheikholeslami, R. (2011). "Composite scale formation and assessment by the theoretical Scaling Potential Index (SPI) proposed previously for a single salt." Desalination **In Press, Corrected Proof**.

[10] Sheikholeslami, R. and H. W. K. Ong (2003). "Kinetics and thermodynamics of calcium carbonate and calcium sulfate at salinities up to 1.5 M." Desalination **157**(1-3): 217-234.

[11] Song, L., S. Hong, et al. (2002). "Simulations of Full-Scale Reverse Osmosis Membrane Process " Journal of Environmental Engineering **128**(10): 960-966.