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Reverse Osmosis Membrane Scaling Inhibition using Kinetic Degradation Fluxion Media

RESEARCH

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ABSTRACT

Membrane fouling can lead to reduced efficiency, increased operating costs, and shorter membrane life, which can ultimately impact the quality of potable water produced from seawater. The use of Kinetic Degradation Fluxion (KDF) media as a pretreatment method is promising because it can potentially reduce fouling caused by $CaCO_3$ scaling and improve the performance of RO membranes. The study's methodology, which involves comparing two identical reverse osmosis systems with and without KDF pretreatment, is appropriate and well-designed. By comparing the salt rejection and permeability flow of the two membrane systems, the study can provide valuable insights into the effectiveness of KDF media in reducing fouling caused by CaCO3 scaling. The explanation of how KDF media works to prevent the formation of mineral hardness scale by altering the morphology of the insoluble Ca and Mg carbonate and sulfate crystals and creating a redox environment is helpful in understanding the potential mechanism behind the effectiveness of KDF media as a pretreatment method. By controlling the formation of mineral scale and other contaminants, KDF media can potentially lead to improved efficiency of the RO membrane. Results suggest that KDF media can be an effective pretreatment method for reducing fouling caused by mineral scaling in RO systems. The potential mechanism behind the effectiveness of KDF media is explained, and the observation that only a small number of KDF discs were degraded over the 40-hour period indicates that KDF media can be used for multiple cycles of RO operation, reducing the frequency of media replacement and associated operating costs. The finding that the RO-KDF membrane remained healthy and efficient for 40 hours while fouling was observed in the RO system within 20 hours is also promising, as it indicates that the KDF media can effectively reduce membrane fouling caused by scaling, leading to improved efficiency and extended membrane life. However, further studies can explore the optimal conditions for using KDF media in RO systems to maximize its effectiveness in reducing fouling and extending the lifetime of RO membranes. Investigating the potential for KDF media to reduce fouling caused by other contaminants, such as organic matter or silica, would also be interesting.

Keywords: Kinetic Degradation Fluxion, RO-KDF membrane, fouling

Introduction

Reverse osmosis (RO) is a widely used water treatment technology based on a semi-permeable membrane to remove impurities from water. However, fouling is a major problem that can affect the efficiency and lifespan of reverse osmosis membranes. It is important to implement effective pretreatment methods to remove or reduce potential sizing of materials and other contaminants in the feed water (Mulyawan and Muarif, 2021). Reverse osmosis membrane scaling may occur when poorly soluble salts in the reverse osmosis element are concentrated beyond their solubility limits (Robinson, et. al 2016). Calcium carbonate ($CaCO_3$) is a common source of measurement in reverse osmosis membranes, due to its rapid sedimentation rate and the fact that many natural water sources are saturated with respect to $CaCO_3$. When water with high concentrations of sparingly soluble salts, such as calcium carbon-

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ate, is passed through an RO membrane, the salts can become concentrated beyond their solubility limit, leading to the formation of solid deposits on the membrane surface. This can reduce the effectiveness of the membrane and lead to decreased permeate flow, increased pressure drop, and other related issues that can affect the performance and lifespan of the RO system. In order to prevent scaling and maintain the performance of the RO membrane, it is important to implement effective pretreatment methods to remove or reduce the concentration of scaling potential substances from the feed water. This can include physical, chemical, or biological methods to remove suspended solids, dissolved organic matter, and other contaminants that can contribute to scaling. It is also important to carefully monitor the performance of the RO system and take appropriate measures to address any $CaCO_3$ scaling or fouling issues that may arise (Eisheh, and Shoqier, 2017). Fouling is a common problem in membrane technology, including reverse osmosis, and can occur due to various factors such as the feedwater quality, membrane material and structure, and operating conditions. $CaCO_3$ fouling occurs when particles or contaminants in the feedwater accumulate on the surface of the membrane, while internal fouling occurs when these particles or contaminants accumulate within the membrane structure, reducing its permeability. The schematic diagram figuring the surface and internal fouling are shown in Figure 1.

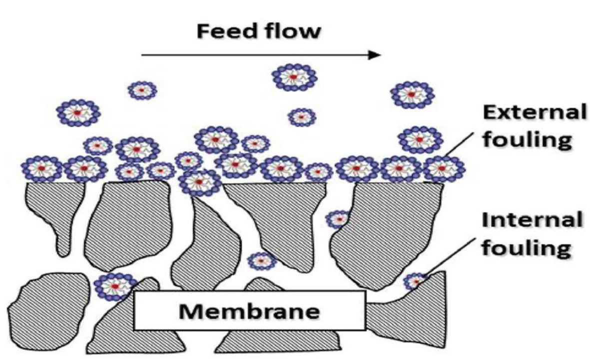

Figure 1: Schematic diagram of reverse osmosis process (SHAMS, 2013)

Fouling can have a significant impact on the performance of the membrane, reducing its permeation flux and salt rejection, and increasing the need for maintenance and cleaning. To address fouling, various pretreatment and cleaning techniques can be used, such as prefiltration, chemical cleaning, and backwashing. In addition, researchers are continually developing new materials and technologies to improve the performance and lifespan of membranes and reduce fouling (Lin, et al, 2016 and She, et al 2016). Fouling can have a range of negative effects on the performance and efficiency of membrane technology, including decreased productivity, lower permeate quality, increased energy demand, the need for additional pre-treatment steps, and increased operating and maintenance costs. Additionally, fouling can shorten the lifespan of the membrane, leading to the need for more frequent replacement and further adding to operational expenses. Therefore, it is important to develop effective fouling control strategies to minimize the negative impact of fouling on membrane technology. In order to avoid $CaCO_3$ scaling and fouling, the pH of the concentrate stream in an RO system should be lower than the pH of saturation (pHs) where the water of the concentrate stream is in equilibrium with $CaCO_3$. This relationship is expressed by the Langelier Saturation Index (LSI) for brackish waters and Stiff and Davis Saturation Index (S&DSI) for sea waters (de Souza et al., 2018 and Robinson et al. 2021). Water treatment professionals often use the index to monitor the potential for scaling and adjust treatment processes to prevent scaling and ensure optimal water quality. Water treatment professionals patented a chemical compound called Kinetic Degradation Fluxion media (KDF). KDF media is a high-purity alloy of copper (Cu) and zinc (Zn) that is used as a prefilter in water purification systems. As water passes through the KDF bed, a redox reaction takes place, which helps to remove impurities such as minerals, metals, dissolved oxygen, and organic materials. KDF is often used in combination with other filtration technologies, such as reverse osmosis, to improve their performance and reduce the need for expensive chemical treatments. KDF media has been found to be effective in reducing chlorine in water, which is important in water treatment, particularly in industrial settings. By reducing chlorine and other impurities, KDF can help prevent fouling and scaling in reverse osmosis water treatment plants, improving their efficiency and lifespan (Eisheh, R., and Shoqier, 2017 and Majdi, et. al., 2019). The study will examine the performance of the two membranes, one with KDF pretreatment and the other without, to determine if KDF media is effective in reducing fouling caused by $CaCO_3$ scaling in reverse osmosis systems. The comparison will be based on the salt rejection and permeability flow of the two membranes.

Materials and Methods

TW30-1812-50 FILMTEC™ RO membrane was used for all experiments. This type of membrane is specifically designed for home drinking water systems and is capable of high salt rejection rates up to 99% with a permeate flow of up to 200 L per day. Additionally, a CuZn filter using KDF-media was used for the study. This filter contains 11 patented reticulated discs with a diameter of 5 cm and a thickness of 1.3 cm for each disc. The discs are flexible, oversized, lightweight, and environmentally friendly. They also have a porous nature, making them easy to install.

For each test in the study, two membranes were used: a reference and a control membrane where the feed water was directed straight through without passing through the KDF media, and a pretreatment membrane where the feed water was passed through the KDF media first. A simplified schematic of the experiment design and layout is shown in Figure 2.

indicated by Eq(1).

LSI = pH – pHs Eq(1)

The tap water used in the experiments had an average concentration of 45 mg/l for Ca and 300 mg/l for HCO_3, but these levels increased to 174 mg/l for Ca and 600 mg/l for HCO_3 in the supersaturated feed solution. The initial pH values for the experiments were in the range of 7-7.5 to achieve a critical LSI value in the range of 0.5-1, indicating a high potential for scaling. The feed tank was kept fully closed to maintain a constant LSI level throughout the experiment.

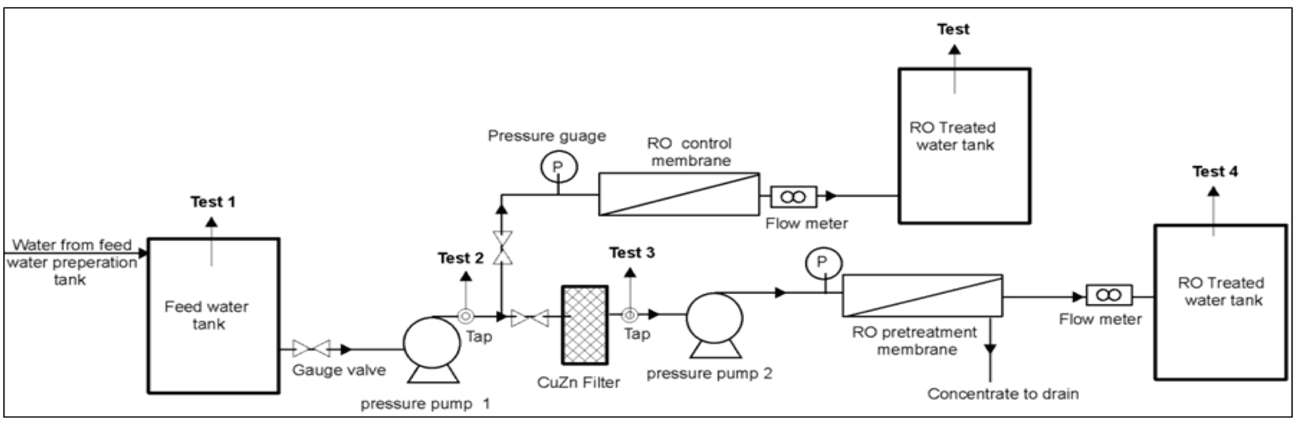

Figure. 2: Experiments schematic design for RO system

The study focused on measuring the effectiveness of KDF media in reducing fouling on RO membranes. Since fouling can lead to a decline in salt rejection and flux rate, these parameters were used to determine the effect of KDF media on reducing fouling. By comparing the salt rejection and permeate flow rate of the RO membrane with and without KDF media, the effectiveness of KDF media in reducing fouling could be roughly assessed. Prior to the experiment, the feed water was analyzed to ensure that the potential for fouling due to factors such as biofouling and mineral fouling was very low.

Results

RO membrane performance parameters in $CaCO_3$ experiments

To prepare a supersaturated $CaCO_3$ feed solution with high scaling potential for the experiments, 16 grams of $CaCO_3$ were dissolved in 50 liters of tap water with rapid mixing. Since CaCO3 is a major source of Ca, adding it to water increases the levels of both Ca and HCO_3, which are fundamental parameters that control the Langelier Saturation Index (LSI) value, as

Salt rejection

RO-only salt rejection

The study found that the optimal salt rejection for the membrane was 96.8%, which was achieved after running the membrane for 3 hours with tap water as the feed solution. When the feed solution was switched to the $CaCO_3$ supersaturated solution, the salt rejection decreased slightly to 95.2% in the 4th running hour and remained relatively constant thereafter (figure 3). Overall, the salt rejection in the RO-only system with the supersaturated $CaCO_3$ solution was in the range of 94.1%-96.8%, which is considered high. The $CaCO_3$ supersaturated solution did not have a significant chemical effect on the material and composition of the polyimide membrane, allowing the system to operate for 40 running hours with a high salt rejection capability.

RO-KDF salt rejection

The KDF media used in the RO-KDF system was effective in reducing fouling and maintaining the performance of the RO membrane. Despite being exposed to a supersaturated $CaCO_3$ solution, the salt rejection remained relatively constant for the rest of the 40-hour running period with a range between 95.8% and 96.8% and only a 1% reduction in salt rejection overall. This indicates that the KDF media was successful in reducing fouling caused by the $CaCO_3$ solution and maintaining the performance of the RO membrane.

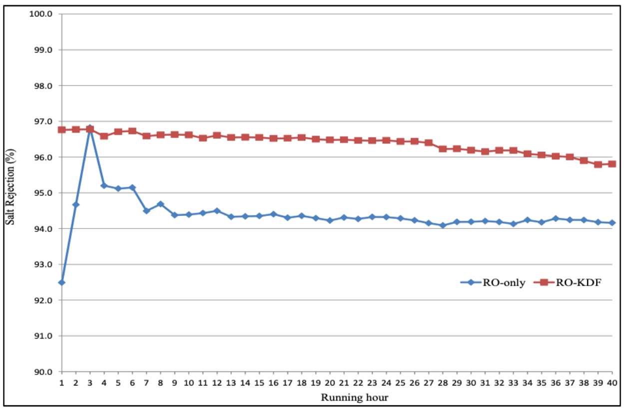

Figure 3: Salt rejection obtained by RO-only and RO-KDF systems.

Permeate flow

Permeate flow is affected by temperature, with higher temperatures generally resulting in higher permeate flow. The experiments in this study were conducted over a range of temperatures from 12.2°C to 28.7°C. The proper permeate flow at each temperature was determined by plotting the typical permeate flow at 60 psi, in accordance with company recommendations.

RO permeate flow

The maximum permeate flow rate of 12 L/h was obtained in the first hour of running using tap water with negative LSI. However, after switching to the $CaCO_3$ supersaturated solution, the maximum permeate flow rate was reduced to 11 L/h in the 7th hour of running. A backwashing operation was performed in the 13th hour of running, which increased the permeate flow rate to 12 L/h by partially removing precipitation and deposition within the membrane. After 22 hours of running, the permeate flow rate decreased to 9 L/h, and backwashing was performed again in the 23rd hour, leading to better performance and an increase in permeate flow rate. However, after 33 hours of running, backwashing became ineffective due to the strong attachment of the particles, resulting in reversible fouling being transformed into an irreversible fouling layer that cannot be removed by physical cleaning methods. In the $CaCO_3$ experiments, the minimum permeate flow rate was 7 L/h, which represents a 41% reduction in permeate flow compared to the maximum permeate flow rate achieved in the first hour of running. This reduction in permeate flow is a strong indicator of fouling, specifically scaling caused by the $CaCO_3$ supersaturated solution used as the feed solution. It is important to note that this reduction in permeate flow is significant, as a 15% reduction in permeate flow is enough to suggest fouling. Additionally, since the feed water analysis indicated low potential for other types of fouling such as metal fouling, microbial fouling, and colloidal fouling, scaling caused by the $CaCO_3$ supersaturated solution is the most likely culprit for the fouling. The total passing feed solution of 1250.5L was processed by the RO system during the 40 running hours. Of this amount, 393.5L was produced as permeate flow, while the remaining amount was the concentrate. The average permeate flow for the running hour was 9.8L, while the average concentrate was 21.4L. This suggests that the system was able to produce permeate flow at a rate of approximately 44% of the feed flow. It also suggests that the system was able to concentrate the feed solution approximately 2-fold.

RO-KDF permeate flow

The RO-KDF system was able to maintain its maximum permeate flow of 12 L/h for the first 18 running hours (figure 4) , despite being exposed to a supersaturated $CaCO_3$ solution. This is likely due to the KDF media's ability to reduce fouling and maintain the performance of the RO membrane. However, after 22 running hours, an 8% reduction in permeate flow was observed, indicating some level of fouling. Fortunately, the second backwashing operation was able to restore the system's maximum permeate flow again to 12 L/h, suggesting that physical cleaning methods like backwashing can be effective in removing fouling and restoring system performance.

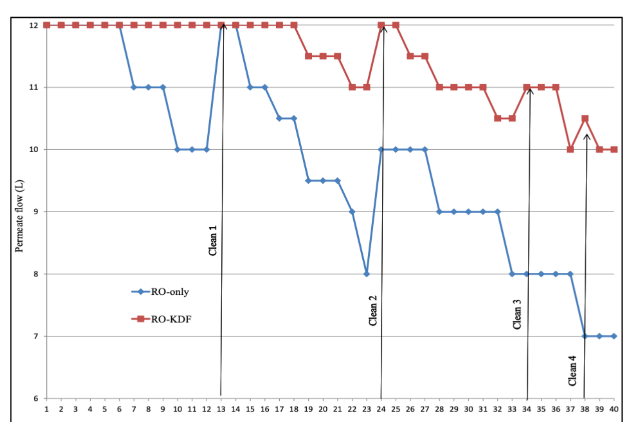

Figure 4: Permeate flow produced by RO-only and RO-KDF systems.

Based on the results, the RO-KDF system was able to maintain its maximum permeate flow of 12 L/h for the first 18 running hours, and despite experiencing an 8% reduction in permeate flow after 22 running hours, the second backwashing operation was able to restore the system's maximum permeate flow again to 12 L/h. The maximum reduction of permeate flow in the RO-KDF system was only 16% with 10 L/h, and this value was measured in the last 2 running hours, indicating that fouling was still reversible. The experiments ended after 40 running hours, with a total passing feed solution of 1382L, 458L were permeate flow and 924L were concentrated. The average permeate flow for the running hour was 11.5L, while it was 22.2L for concentrate. These results suggest that the RO-KDF system was able to produce permeate flow at a rate of approximately 33% of the feed flow and concentrate the feed solution by approximately 2-fold.

Scaling inhibition by KDF

The KDF media was able to prevent the formation and accumulation of mineral hardness scale, which is primarily composed of $CaCO_3$, by altering the morphology of insoluble Ca and Mg carbonate and sulfate crystals to relatively small, evenly shaped, and rounded grains and rods. As a result, there was no change in the water composition and the permeate flow results showed that the KDF media improved the efficiency of the RO membrane. This change in crystal morphology is due to the redox reaction that occurs on the surface of the KDF media , which results in the formation of small, spherical crystals that are less likely to adhere to surfaces and form scaling. The KDF media is able to achieve this through its unique combination of copper and zinc, which creates a redox environment that helps control the formation of mineral scale and other contaminants in the water. This is why the KDF media was effective in preventing fouling and maintaining the performance of the RO membrane, even when exposed to a supersaturated $CaCO_3$ solution.

Discussion

The use of KDF media as a pretreatment step in RO systems has shown promising results in preventing fouling and scaling caused by $CaCO_3$. The redox environment created by the combination of copper and zinc in the KDF media has been found to alter the morphology of the insoluble Ca and Mg carbonate and sulfate crystals, resulting in small, evenly shaped, and rounded grains and rods that are less likely to adhere to surfaces and form scaling. The $CaCO_3$ experiments demonstrated that the RO-KDF membrane was able to maintain high efficiency and prevent fouling for a longer period of time than the RO-only system, with the KDF media extending the lifetime of the membrane for at least one cycle. Additionally, the concentrate produced by the RO-KDF system had less scaling potential, indicating that the fouling in the whole plant could be minimized. However, it should be noted that the KDF media has a limited ability in $CaCO_3$ inhibition, and 11 discs were required to extend the lifetime of the membrane once only. This suggests that KDF media may not be a cost-effective solution for long-term use in RO systems for $CaCO_3$ inhibition. Overall, further studies are needed to explore the effectiveness of KDF media as a pretreatment step for other types of fouling and scaling in RO systems and to evaluate its cost-effectiveness in comparison to other pretreatment methods.

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