Study on the performance of a scale inhibitor during horizontal-tube falling film evaporation of seawater

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Abstract. Fouling on heat transfer surfaces is a severe problem and a complex phenomenon in multiple-effect distillation plants with horizontal tube falling film evaporators. In general, the scale on heat transfer surfaces is effectively prevented by adding scale inhibitors in large LT-MED seawater desalination plants. This paper presents an experimental study on the performance of a scale inhibitor with different seawater spray temperatures and salinities during falling film evaporation outside the horizontal tubes. The scale inhibitor is developed by the Institute of Water Treatment of Nanjing Tech University. Experiments are performed under the seawater temperature of 70°C, 80°C and 90°C and the salinity of 30g/kg, 60g/kg and 80g/kg. The dosage of the scale inhibitor is 6mg/L. The titanium tubes are used inside the evaporator and Dalian local seawater is selected as the working agent. The scale growing curves under different conditions are obtained through weighting the amount of the scale formed at different periods. The seawater temperature and salinity have a certain influence on the performance of the scale inhibitor during the horizontal-tube falling film evaporation. As the seawater spray temperature rises, the scale inhibition efficiency decreases. With the increase of salinity, the scale inhibition efficiency decreases.

1. Introduction

With the rapid development of industry, the world is facing serious freshwater shortage. There are lots of ways to solve this problem, among which desalination is an effective one. Thermal desalination, with multi-stage flash distillation, multiple-effect distillation, and vapor compression distillation as cores, is the main desalination technology in the world. Compared with multi-stage flash distillation and vapor compression distillation, multiple-effect distillation has a broader application prospect for its high efficiency of thermal utilization, simple seawater pretreatment and low operating cost. In the process of multiple-effect distillation, scaling on heat transfer surfaces will affect the heat transfer efficiency and limit the top brine temperature. To solve this problem, scale inhibition and descaling are often combined in practice [1]. The application of scale inhibitors is effective to improve the operating efficiency, reduce the number of times of pickling and extend the life of the equipment.

Scale inhibitors are a class of specialty chemicals that are used to prevent the formation and precipitation of scale on equipment surfaces. It has been widely used in a variety of fields, such as chemical industry, petroleum, water treatment, printing and dyeing, paper making and textile. Suresh Patel [2] evaluated the synthesized polyacrylic acid scale inhibitors in laboratory and actual operation. According to the results of the laboratory, Belgard EV2035 and Belgard EV2030 were formulated with anti-fouling agents in the actually operating MSF devices. The dosage was 2 mg•L-1, and the
dosage of the Begard EV2050 scale inhibitor was 3 mg•L\(^{-1}\) in MED, all of which had a high scale inhibition efficiency.

Ali A. Al-Hamzah [3] studied four novel polyacrylic acid scale inhibitors (HIB-PAA \([\text{Mn}=1400]\), HIB-PAA \([\text{Mn}=3600]\), CIB-PAA and HDIB-PAA) and three commercial scale Inhibitors (Belgard EV-2030, Sokalan PM10i and Albrivap DSB (M)). The scale inhibitors of moderately hydrophobic, low molar mass PAA (HIB-PAA, \(\text{Mn} = 1400\)) and CIB-PAA, \(\text{Mn} = 1700\)) were more effective than other HIB-PAA and the best commercial scale inhibitor Belgard EV2030. It was indicated that these two new scale inhibitors were suitable for thermal desalination plants.

Haichun Zhang [4] studied the scale inhibiting performance to calcium carbonate of the polymer inhibitor PAMA by national standard GB/T16632-1996. Effects of PAMA amount, \(\text{Ca}^{2+}\) concentration, alkalinity and temperature to scale inhibiting percentage were relatively large. The scale inhibiting percentage increased with the PAMA amount and decreased with the increase of \(\text{Ca}^{2+}\) concentration, alkalinity and temperature. Effect of constant temperature time was relatively small. Results of seawater concentration method showed that the scale inhibiting percentage increased with the PAMA amount. Effect of temperature and constant temperature time to scale inhibiting percentage was larger than the concentration times. The scale inhibiting percentage decreased with the increase of temperature, constant temperature time and concentration times.

Zhanhui Shen [5] studied the developed special scale inhibitors for multi-effect distillation desalination. The performance of the inhibitors was evaluated in this research under the background of thermal desalination. The mechanism of inhibition was discussed through two aspects. Five inhibitor formulas were obtained, and its performance was evaluated through the national standard method (GB/T 16632-2008) and CMD. And the action mechanism of scale inhibitor was studied through analyzing the scale samples using Scanning Electron Microscopy (SEM), X-ray diffraction (XRD) and Particle Size Analysis (PSA). When the inhibitor concentration ranged from 6mg/L to 15mg/L, the inhibition rate kept at from 65% to 70%. SEM results showed the scale appearance changed totally under the action of scale inhibitor.

Xu Han [6] studied the anti-scaling property of synthesized hydrolyzed poly-malefic anhydride (HPMA) through the national standard method and copper precipitation method. It was confirmed that the molecular weight of the synthesized HPMA was 625 by gel permeation chromatograph (GPC). The national standard method experiments showed that HPMA fits the classic definition of being threshold scale inhibiting compound. In the copper precipitation experiments, the synthesized HPMA could make the characteristic of the scale modified, so that the growth and attachment of the scale modified on the surface of the heat-exchange coppers became harder. SEM and XRD results showed that the original characteristic of the scale changed into irregular-shaped soft-fouling properties of flocculation with the vaterite being formed, so that the scale was not easy to deposit or attach on the surface of equipment. The application prospect of HPMA in thermal desalination process was foreseeable.

Jizhuang Yang [7] studied the fouling trend of different ions which tend to scale in brine under the condition of different concentration ratios. The main constituents of scale inhibitors that had shown good efficiency in controlling scale formation used in present desalination plants were analyzed and their performance was studied under concentration ratio at 2.5. The addition of inhibitor could reduce the amount of deposition in evaporator. Furthermore, the scale inhibitor showed better performance in preventing calcium ion and sulfate ion from depositing under high concentration ratio. It was also found that the amount of scale began to decrease with increasing dosage of the inhibitor. The amount of scale met the operation requirements of the present desalination plant in the condition of the dosage of 4.28mg/L for the inhibitor.

Xinbing Yuan [8] used 1.5 times concentration of sea water as experimental object. The scale inhibition and dispersion performance of itaconic-styrene sulfonic acid sodium-acrylic acid copolymer was investigated by spectrophotometer and complexometric titration, and crystal form of calcium sulfate fouling sample was analyzed by SEM. The results showed that the copolymer had good scale inhibition and dispersive effect. The copolymer could also change the characters of the scale crystal,
loose and porous, which made it not easy to deposit on the surface. Otherwise, the copolymer had
good thermal stability, which could satisfy the operation requirements of thermal seawater
desalination equipment.

Scholars at home and abroad had carried out some theoretical and experimental researches and
achieved some outcomes in scale inhibition. However, up to now, the research on specialized scale
inhibitors for multiple-effect evaporation was not enough. In this paper, the performance of a special
scale inhibitor during the horizontal-tube falling film evaporation is experimental investigated.

2. Experimental system
The experimental system is shown in Figure 1. The tube material is titanium. The local seawater in
Dalian is chosen as the working fluid. This experiment is performed under the atmospheric pressure.
The seawater is preheated in a heating tank to the required temperature by an electric heater, and then
flows into a spray pipe inside the falling film evaporator. It sprays on the outside surfaces of the
horizontal heating tubes. After evaporation, the concentrated seawater flows into a storage tank, and
then is drained off.

![Diagram of the experimental system.](image1)

Figure 1. Diagram of the experimental system.
1.pump 2.Valves 3.data acquisition instrument 4.evaporator
5.flow-meter 6.Thermocouples 7.low power electrical heater
8.storage tank 9.heating tank 10.high power electrical heater

The scale mass ($\Delta M$) formed outside the heating tube surface is measured by an electric mass
balance (with an accuracy of 0.01 mg). The seawater temperature and the heat transfer surface
temperature are measured by thermocouples (with an accuracy of 0.01 $^\circ$C). The seawater salinity is
measured by a salinometer (with an accuracy of 1.0 mg/L). The scale inhibitor is developed by the
Institute of Water Treatment of Nanjing Tech University. The dosage of the scale inhibitor is 6 mg/L.

The scale inhibition ratio ($Y$) is calculated according to the following formula:

$$Y = \frac{(M_1 - M_2)}{M_1} \times 100\%$$  \hspace{1cm} (1)

where $M_1$ is the scale mass on the titanium tube without the scale inhibitor; $M_2$ is the scale mass on
the titanium tube with the scale inhibitor.
3. Results and analysis

3.1. Scale growing curves at different seawater temperatures

Figure 2. The scale growing curves with the seawater temperature of 70°C.

Figure 3. The scale growing curves with the seawater temperature of 80°C.

Figure 4. The scale growing curves with the seawater temperature of 90°C.
The spray density is 0.03 kg/(m·s). The heat transfer temperature difference between the tube surface temperature and the seawater temperature is 3 °C. The seawater temperatures are 70 °C, 80 °C and 90 °C. The seawater salinity is 80 g/kg. The experimental results are shown in Figure 2, Figure 3 and Figure 4.

As shown in Figure 2, it can be seen that the amount of scale on the surface of the titanium tube significantly reduced after the use of the scale inhibitor. The scale inhibition ratio reaches nearly 76%. As shown, the scale inhibition ratio reaches nearly 69% in Figure 3 and the scale inhibition ratio reaches nearly 54% in Figure 4. As the spray temperature rises, the scale inhibition efficiency decreases.

The overall fouling process is usually considered to be the net result of two simultaneous sub-processes: a deposition process and a removal process. All the sub-processes can be summarized as the formation of scale, the transport of scale, the attachment reaction, the removal of the scale deposit and the transport from the deposit-fluid interface to the bulk of the fluid. When seawater spray temperature rises, the formation of scale, the transport of scale, the attachment reaction, the scale deposit and the transport from the deposit-fluid interface to the bulk of the fluid are enhanced. Even if the thermal motion of the scale inhibitor also increases, the net effect of seawater spray temperature rising results in the amount of the scale on the tube surface increasing and the scale inhibition efficiency decreasing.

3.2. Scale growing curves at different salinities

The spray densities is 0.03 kg/(m·s). The heat transfer temperature difference between the tube surface temperature and spray temperature is 3 °C. The spray seawater temperature is 80 °C. The salinities of seawater are 30 g/kg, 60 g/kg and 80 g/kg. The experimental results are shown in Figure 5, Figure 6 and Figure 7.

As shown in Figure 5, the scale inhibition ratio reaches nearly 73%. The scale inhibition ratio reaches nearly 70% in Figure 6 and 69% in Figure 7. As the seawater salinity rises, the scale inhibition efficiency decreases slightly. It can be explained that when the seawater salinity rises, the scale ions increases, so the amount of scale increases. Under the same dosage of the scale inhibitor, the scale inhibition efficiency decreases.

![Figure 5](image-url)  
*Figure 5.* The scale growing curves with the seawater salinity of 30 g/kg.
4. Conclusions
The seawater temperature and salinity have a certain influence on the performance of the scale inhibitor under the same dosage during horizontal-tube falling film evaporation. As the seawater temperature rises, the scale inhibition efficiency decreases. With the increase of salinity, the scale inhibition efficiency decreases.

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