Pilot Evaluation of DSA Anode Electrochemical Scaling Applied in a Cooling Water Circulation System

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Keywords: Dimensionally Stable Anode, Current Density, Inter-electrode Distance, Specific Energy Consumption.

Abstract. Scale deposition in circulate cooling water system is a terrible problem which could result in the reduction of heat transfer efficiency and increasing of operational consumption. In this paper, based on the Lab scale experiment, the DSA electrodes was evaluated in cooling water scaling by pilot experiment. The experimental results indicated that, the hardness removal rate appeared approximately linear relationship with the current density, and the hardness removal rate increased rapidly with the increasing of the residence time and then tends to be stable. According to the scaling requirement and economic consumption in practical application, under the experimental condition, current density of 25.56A/m² and the residence time of 4min was the best working condition with the hardness removal rate of 22.87%. The research results could provide important practical basis for the development, design and commissioning of electrochemical equipment in the future.

Introduction

Scale deposition results problems such as heat exchangers efficiency decay, membrane clogging, pipe blocking, equipment life shortening, etc.[1]. The traditional scale control process applied in water treatment is based on the dosage of anti-scalants which is able to restrain scale precipitation up to a certain degree, and among with the dosage of these kinds of chemical compounds, this technique would result in harmful effects on environment, high power consumption and expenses to operate the treatment system[2-4].

In recent years, a electrochemical technique to control the scaling potential of water circulating was applied in cooling water system by the precipitation of hardness forming ions on the cathode zone, which can decrease the water hardness of the system[5-7]. Dimensionally stable anode (DSA), which has excellent corrosion resistance, high electrocatalytic activity, and stable mechanical characteristics, has been probed to be applied in water scaling system[8-10]. Compared with other methods, this electrochemical scale removal process offers many advantages such as accessibility to automation, environmental compatibility, no need to chemical dosage, convenient process control, and convenient wastes handle[11,12].

The former Lab scale experimental results has been indicated that, the main influencing factors of DSA electrochemical scaling process are electrode spacing, current density, and electrolysis time. In this study, to prove the conclusion drawn in the Lab, pilot scale experiments have been put into effect to evaluate the effect of the above factors in a circulate cooling water system.

Materials and Methods

Pilot Experimental System

The experimental system consisted of a pilot electrolyser which electrodes dimension is 300x500mm², and a DC power supply. Between the cathode and the anode plate, there exits 20 cm space in the electrolyser. The DC power supply (Yizhan Electronic Instrument Co., Ltd, Shenzhen of China) was used to supply power at a constant current intensity. The cathode was a 300x500mm² ferric plated and the anode plate was a same dimension Ti/IrO₂-RuO₂ electrode. The pilot electrolysis experimental system was shown as Fig. 1.
Raw Water

In this paper, the raw water characterized by Ca$^{2+}$ concentration of 200~250mg/L was circulate cooling water of a central air conditioner system in an airport, the experimental system pressure and inlet flux were regulated by regulating inlet valve.

Analysis Methods

Determination of Ca$^{2+}$ in water samples by EDTA complexometric titration. Three parallel samples were taken for each working condition during the experiment[13]. The minimum detection concentration of this method is 0.05 mmol/L, and the repeatability deviation is ±0.04 mmol/L.

Results and Discussion

Current Density

At the beginning of the experiment, the influent flow rate was adjusted to 261 L/h. At this time, the hydraulic retention time (HRT) of the cooling water was 2 min, the current was 23 A, and the current density (J) corresponding to the current intensity was 25.56 A/m$^2$. After 1 h of stable operation, the treated water was sampled and then analyzed. In this study, a total of 7 sets of experiments were carried out under different influent flow conditions. Figure 2. illustrated an approximately linear relationship with the current density, which was different from the laboratory dynamic test results. The total water hardness referred to the total amount of Ca$^{2+}$ and Mg$^{2+}$ in the water, and the actual circulating cooling water contained a large amount of Mg$^{2+}$. The results of Kai Zeppenfeld showed that the deposition rate of brucite in the cathode plate was proportional to the square of the current density. As the current density increased, the increase rate of the brucite deposit increased. The increase of Mg$^{2+}$ removal rate increased with the increase of current density; the previous laboratory dynamic test showed that the increase of Ca$^{2+}$ removal rate increased the current density and decreased, and the two functions canceled each other out, which was the hardness removal rate and the current density is linear.

![Figure 2. Correlation between current density and hardness removal rate.](image-url)
In actual circulating cooling water, suspended solid such as dust in the water would induce nucleation of hard or slightly soluble salt and provided a site for the growth of crystals. A large number of crystals adhered to these suspended solids and continued to grow into large crystals. These large crystals sank to the bottom of the reactor by gravity after they reach a certain mass. The presence of suspended solid in the circulating cooling water allowed the scaled ions to crystallize without migration to the cathode plate, greatly reducing the effect of mass transfer on hardness removal.

**Inter-electrode Distance**

The length of HRT was also critical for the hardness removal rate. During the test, the HRT was adjusted by controlling the flow rate. Rearranged and analyzed the data to obtain hardness at different current densities. The removal rate varied with the HRT was shown as Fig.3.

![Figure 3. Correlation between hydraulic retention time and hardness removal rate.](image)

As shown in the figure, as the HRT was extended, the hardness removal rate continued to increase and the growth trend became more and more stable, which was consistent with the conclusions drawn from the laboratory dynamic test. When the HRT was 2min~4min, the increase rate of hardness removal rate was higher; in the range of HRT of 4min~5min, the hardness removal rate was prolonged with the HRT as the influent flow rate became closer and closer. The increase was no longer obvious, so the optimal HRT was 4 min.

**Specific Energy Consumption**

Not only the removal of hardness, but also the energy consumption determined the optimum operating conditions of the reactor. Both current density and HRT had a large impact on energy consumption. By calculating the specific energy consumption under various operating conditions and analyzing and sorting, the influence law of current density and HRT versus energy consumption in the pilot test was investigated. Fig. 4 and Fig.5 shown the correlation between specific energy consumption and current density and HRT in the pilot test.

It could be seen from Fig. 4 that in the pilot test, the specific energy consumption increased linearly with the increase of the current density. Increasing the current density in actual operation would greatly increase the energy consumption and increase the operating cost. Figure 5 shown the correlation between specific energy consumption and HRT. It could be observed that the energy consumption gradually decreased with the extension of the HRT at the beginning. When the HRT was 4min, the specific energy consumption was the lowest, and then the energy consumption increased with the increase of the HRT. Therefore, the flow rate was adjusted so that the HRT was 4 minutes, and the energy efficiency ratio of the equipment was the highest.
Determination of the Best Working Condition Parameters

Under the pilot experiment conditions with which current density ranged from 25.56 A/m² to 100 A/m², when the HRT was 4 min, the hardness removal rate increased little with the increase of current density. When the current density was 25.56 A/m², the hardness removal rate was 22.87%, and the current density was increased to 100 A/m². The hardness removal was 25.35%. In comparison, it only increased by 2.48%, but the energy consumption increased by 6 times. Therefore, the optimum operating conditions were a current density of 25.56 A/m² and a dwell time of 4 min.

Conclusion

The comprehensive conclusion of this experimental study leads to the following conclusions: The hardness removal rate is approximately linear with the current density, and the former increases as the latter increases; The hardness removal rate increases rapidly with the increase of HRT and then tends to be gentle. The best HRT is 4 min; Specific energy consumption increases linearly with increasing current density. The specific energy consumption showed a trend of decreasing first and then increasing with the increase of the HRT. When the HRT was 4 min, the specific energy consumption was the smallest. Taken together, the optimal HRT is 4 minutes; According to the hardness removal rate requirement and economic principle in practical application, when the current density is 25.56 A/m² and the HRT is 4 min, it is the best working condition, and the hardness removal rate is 22.87%.

Acknowledgements

This study was financially supported by Key Research and Development Project of Shandong Province (2016GSF117007). The authors would like to thank reviewers and the Manuscript Editors for their constructive comments on the manuscript.
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