

Application of Electrochemical Technology in Circulating Cooling Water Treatment for Thermal Power Plants

Yonglong Lan, Min Qiu and Zhan Xu

Huadian Electric Power Research Institute CO., Ltd., Hangzhou, China

Abstract: Circulating cooling water systems are crucial auxiliary systems in thermal power plants, and their stable operation is essential for ensuring the safe and efficient production of power generating units. Traditional chemical dosing methods, while offering some degree of control over scaling, corrosion, and biofouling, are increasingly limited by their high costs, secondary pollution, and limited effectiveness in removing hardness ions. Electrochemical treatment technology, by creating a highly alkaline environment at the cathode, precipitates hardness ions at the source. Simultaneously, it generates strong oxidizing agents at the anode to kill bacteria and algae. In practice, this technology effectively increases the concentration ratio of circulating cooling water, significantly reduces sewage discharge, and can completely replace chemical agents. It offers significant advantages in water conservation, emission reduction, and green operation. This study focuses on the main principles, key component design, and influencing factors of electrochemical technology. Based on empirical applications in typical thermal power plants, its economic and environmental benefits are analyzed and summarized. The results show that the use of this technology can increase the concentration ratio of circulating cooling water to more than 7 times, save more than 500,000 tons of water annually, and has a short payback period on investment. It has broad application prospects in thermal power generation and other industrial fields.

Keywords: Thermal power plant; Circulating cooling water; Electrochemical treatment; Descaling; Sterilization and algae removal; Water saving and emission reduction.

1. Introduction

Circulating cooling water systems play a vital role in thermal power plants, accounting for approximately 80% to 90% of total industrial water consumption^[1-2]. The core function of this system is to provide cooling for key heat exchange equipment, such as condensers, by efficiently exchanging heat to reduce equipment temperature, thereby ensuring and improving the thermal efficiency of the generating unit. However, during the circulation process, the water continuously evaporates and concentrates, leading to a continuous increase in the concentration of minerals, dissolved oxygen, dust, and bacteria in the water. This easily triggers a series of problems such as scale deposition, metal corrosion, and microbial growth^[3-5]. These issues not only significantly reduce heat exchange efficiency and increase energy consumption but can also lead to equipment damage, production interruptions, and even safety accidents.

Currently, the widely used circulating cooling water treatment method in thermal power plants is chemical treatment, which involves adding scale inhibitors, corrosion inhibitors, and biocides to the circulating cooling water system to inhibit scaling, corrosion, and microbial growth^[6-7]. Although this method is widely used, its inherent drawbacks are becoming increasingly prominent, mainly including: (1) high cost of chemicals; for 2*200MW unit, the annual cost of chemical consumption is close to 400,000 RMB; (2) chemical residues may cause environmental pollution, increasing the difficulty of subsequent drainage treatment; (3) limited removal of hardness ions and chloride ions in circulating cooling water, limiting the increase of concentration ratio.

Under the background of the national "dual carbon"

strategy and industrial green transformation, improving the utilization rate of circulating cooling water in thermal power plants and reducing wastewater discharge are of great significance. Electrochemical water treatment (EWT) functions as a representative active treatment technology, capable of precipitating scale from circulating cooling water in a solid form without the addition of chemical reagents. This capability substantially mitigates the scaling tendency within the circulating cooling water, thereby ensuring the cleanliness of heat exchanger surfaces and the preservation of heat transfer efficiency. Moreover, EWT facilitates an increase in the concentration ratio of the circulating cooling water, which in turn reduces the quantity of wastewater discharge (blowdown). This leads to effective water resource conservation and is consistent with prevailing national policies focused on ecological protection, environmental sustainability, and carbon emission reduction (dual-carbon policies).^[8-11] A thorough examination of the mechanisms and application outcomes of this technology within the circulating cooling water environment of thermal power plants provides robust technical support for the enhancement and optimization of large-scale industrial water treatment processes.

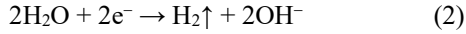
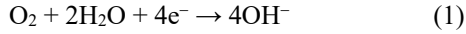
2. Principles and Advantages of Electrochemical Circulating Cooling Water Treatment Technology

2.1. Basic Mechanism of Electrochemical Descaling and Sterilization

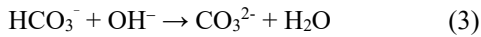
The core of electrochemical treatment lies in achieving different reaction environments at the cathode and anode:

In the electrochemical treatment system, the cathode region

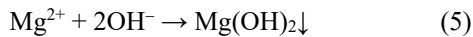
is the main site for hardness ion removal^[9-12]. There are two main reactions in the cathode region that produce OH⁻, oxygen reduction reaction and hydrogen evolution reaction, as shown in equations (1) and (2) .



In the actual treatment process, due to cathodic polarization, the hydrogen evolution reaction shown in equation (2) becomes the dominant reaction for OH⁻ production. HCO₃⁻ in the circulating cooling water migrates to the cathode surface under mass transfer, and reacts with OH⁻ to form CO₃²⁻, as shown in equation (3):

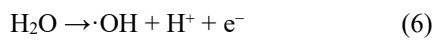


Simultaneously, Ca²⁺ and Mg²⁺ in the circulating cooling water migrate to the cathode under mass transfer and electric field effects, and react with CO₃²⁻ and OH⁻ to form CaCO₃ and Mg(OH)₂ precipitates, respectively, as shown in equations (4) and (5) :

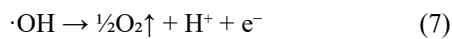


Through this series of reactions, the hardness and alkalinity in the circulating cooling water are effectively removed, reducing the risk of scaling.

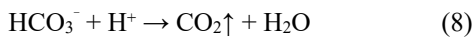
The main electrochemical reaction in the anode region is the electrolysis of water, producing highly oxidizing ·OH radicals and H⁺ ions, forming a highly acidic region, as shown in equation (6) :



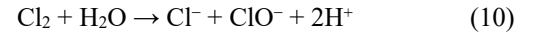
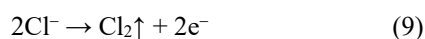
If the formed ·OH radicals are not consumed in time, they will self-recombine to form oxygen, as shown in equation (7):



In addition, HCO₃⁻ migrates to the anode under the electric field effect and reacts in the highly acidic region to form CO₂, further reducing the alkalinity in the water, as shown in equation (8):



When chloride ions are present in the circulating cooling water, highly oxidizing ClO⁻ is generated in the anode region, further reducing the pH of the solution, as shown in equations (9) and (10) :



These strong oxidizing substances (·OH, ClO⁻, etc.) can oxidize organic matter in the circulating cooling water, kill bacteria and algae, and effectively inhibit microbial growth .

2.2. Comparative Analysis with Traditional Chemical Dosing Methods

Compared with chemical dosing methods, electrochemical water treatment technology has the following significant advantages: (1) Environmental friendliness: No large doses of chemical agents are required, avoiding secondary pollution to the environment caused by chemical residues and their gradual accumulation; (2) Active hardness removal: The highly alkaline environment generated by the cathode can precipitate hardness ions from the water at the source, while ordinary chemicals only prevent crystalline deposits from depositing on the exchange surface and cannot significantly reduce the hardness in the water; (3) Increased concentration ratio: After the hardness and biological content of the water are greatly reduced, the cooling water can be circulated for more cycles, and the amount of sewage discharge is significantly reduced; (4) Low operating cost: In addition to the initial investment, the main consumption in the later stage is electricity, and with the optimization of equipment and processes, the energy consumption per unit of water can be further reduced; (5) Easy to automate control: It can be combined with sensors to achieve precise measurement and control, reducing manual intervention and management costs.

3. System Design and Key Influencing Factors

3.1. Electrode Materials and Equipment Structure

3.1.1. Anode Materials

The anode is a key component of the electrochemical system, and its main function is to form a highly acidic region and generate strong oxidizing substances. Common anode materials include graphite electrodes, noble metal electrodes, titanium-based metal oxide electrodes (DSA electrodes), and boron-doped diamond electrodes (BDD electrodes) . Considering cost and performance, titanium-based DSA electrodes, especially titanium-based ruthenium-iridium composite oxide electrodes (Ti/RuO₂-IrO₂), are often selected for circulating cooling water treatment systems in thermal power plants. This type of electrode has a high chlorine evolution potential and good electrocatalytic activity, and exhibits excellent sterilization and algae removal effects in circulating cooling water treatment^[13-15].

3.1.2. Cathode Material Selection

The cathode is the main site for hardness ion removal, and the cathode material, surface condition, and area significantly affect the descaling efficiency. Considering cost and processing performance, stainless steel, cast iron, or carbon steel are often selected as cathode materials in industrial circulating cooling water treatment systems . Studies have found that cathodes with smooth surfaces are not only conducive to the deposition of scale but also facilitate the removal of scale . To improve descaling efficiency, a multi-grid coupled cathode design can be used, utilizing its unique multi-layer structure to generate a self-synergistic effect and improve the descaling rate of the electrochemical water

softening system. In addition, appropriately increasing the cathode area can reduce the cathode contact resistance and decrease energy consumption during operation. Therefore, the internal structure of the electrochemical descaling equipment should be optimized to maximize the available cathode area^[16-20].

3.1.3. Power Supply System

The power supply system is an important part of electrochemical treatment technology. Common power supply methods include DC constant voltage, DC constant current, pulsed constant voltage, and pulsed constant current. Currently, DC constant current power supply is mostly used in industrial applications. To extend the service life of the cathode and improve descaling efficiency, a method of alternating high and low current density input can be used to achieve automatic peeling of the scale layer on the cathode surface. Alternatively, polarity reversal (periodic switching of the current polarity between the anode and cathode) can be employed, utilizing the oxygen and H^+ generated by the anode reaction to remove scale from the cathode surface.

3.2. Equipment Form and System Configuration

3.2.1. Electrochemical Device Form

According to the scale cleaning method, electrochemical devices can be divided into manual and automatic types. Manual equipment requires periodic manual cleaning of the reactor scale. Typical forms include open scale-collecting cages and closed descalers. Automatic equipment is equipped with an automatic scraping system. When the system runs to a set state, the internal scraper of the equipment is rotated by a motor to automatically clean the scale.

3.2.2. System Installation Form

Electrochemical systems have two installation modes in circulating cooling water treatment: direct immersion and external operation. Direct immersion involves placing the unhoused electrolysis equipment directly into the circulating cooling water pool. External operation involves introducing the circulating cooling water into external electrolysis equipment for treatment and then returning it to the circulating cooling water pool. For large thermal power plants, external operation systems are preferred, with reasonable pipeline design and flow control to ensure treatment effectiveness. For small circulating cooling water systems, direct immersion equipment can be considered to reduce investment costs.

3.3. Key Factors Influencing Electrochemical Treatment Effectiveness

(1) Current Density: This determines the rate of OH^- production at the cathode and the rate of formation of active substances at the anode. It is a core parameter for treatment efficiency. Too low a current density can lead to unsatisfactory removal rates, while too high a current density can lead to excessive hydrogen evolution and over-chlorination, increasing energy consumption and damaging the electrodes. (2) Water Quality Characteristics: The hardness/alkalinity ratio, chloride ion concentration, pH, and dissolved oxygen significantly affect descaling and sterilization efficiency. If the chloride ion content in the water is moderate, the process of generating ClO^- and Cl_2 at the anode is relatively sufficient, resulting in better sterilization. (3) Flow Field and Mass Transfer: Reasonable spacing

between electrode plates and flow rate design can reduce bubble interference and enhance the migration of reactants and products. Changes in laminar and turbulent flow also affect the distribution of sediment adhesion, requiring comprehensive consideration of equipment scale and treatment requirements to set the optimal conditions.

3.4. Process Flow Design

The typical process flow design for an electrochemical treatment system for circulating cooling water in a thermal power plant is as follows:

(1) Bypass Introduction or Dedicated Pipeline Water Intake: Part of the circulating cooling water is introduced into the electrochemical reaction unit from the bypass of the circulating cooling water system or through a dedicated pipeline. This method can flexibly adapt to different system requirements, and can either treat the entire circulating cooling water flow or only a portion of the bypass flow. (2) Electrochemical Reaction Unit Treatment: The introduced circulating cooling water is treated in the electrochemical reaction unit. In the cathode region, hardness ions in the water precipitate and form scale. Simultaneously, strong oxidizing substances with sterilization and algae removal effects are generated in the anode region. (3) Treated Water Return: The circulating cooling water treated by electrochemistry is returned to the main pipeline or water pool of the circulating cooling water system, mixed with other circulating cooling water, and participates in the cooling cycle. (4) Regular Scraping and Sedimentation: The system regularly starts the scraping device to scrape off the scale deposited on the cathode surface and discharge it into the sedimentation system. The scraping frequency and method can be adjusted according to water quality and system operating conditions to maintain the effective working area and treatment efficiency of the electrodes. (5) Sedimentation Tank Sludge Treatment: The scale and sediment accumulated in the sedimentation tank need to be regularly discharged and properly treated. The sludge discharge cycle depends on the amount of scale produced and the volume of the sedimentation tank. The discharged scale can be recycled or disposed of harmlessly. Taking Huzhou Thermal Power Plant as an example, its electrochemical treatment system adopts a bypass installation method. Specifically, a branch pipe is taken from each of the circulating cooling water return pipes of the two generating units, and they are combined and enter the electrochemical equipment for treatment. The equipment is equipped with four electrochemical reaction units operating in parallel to meet the water treatment demand. In order to effectively collect and treat the scraped scale, the system is equipped with a three-stage sedimentation system around the electrochemical equipment. The operation of the entire system is automatically managed by a PLC control system, which controls the opening and closing of valves and the start and stop of the scraper system through preset programs, and regularly performs scraping and sludge discharge operations.

4. Engineering Application and Economic Benefit Analysis

4.1. Engineering Application Case

A combined-cycle power plant has 2*200MW units with a circulating cooling water volume of approximately 22,000 m³/h. In the past, when using chemical dosing methods, the annual cost of chemical dosing was about 400,000 RMB, the

system concentration ratio was only about 3, the amount of sewage discharge was large, and there was a certain pollution risk to downstream water bodies.

After the transformation, the plant added four electrochemical reaction units on the circulating cooling water return pipeline, adopting bypass treatment and

equipped with an automatic scraper and a three-stage sedimentation system. The online monitoring device includes pH, conductivity, and chloride ion sensors, which can provide real-time feedback to the PLC for regulation. The changes in water quality and quantity before and after electrochemical treatment are shown in Table 1.

Table 1. Changes in water quality and quantity before and after electrochemical treatment

Parameter	Water Replenishment	Chemical Treatment	Electrochemical Treatment	Control Indicators
pH	7.5	8.2	8.4	≤ 9.5
Conductivity ($\mu\text{S}/\text{cm}$)	523	2380	3700	-
Total Hardness (mg/L)	176.2	415	856	-
Total Alkalinity (mg/L)	94.2	267	134	-
Chloride (mg/L)	126.5	387.2	803.4	≤ 1000
Water Replenishment (m^3/h)	-	461	359	-

The operation results show that: the concentration ratio has increased to more than 7, water replenishment and sewage discharge have been greatly reduced, and the sewage discharge has been reduced by about 70%; the addition of scale inhibitors, biocides, and other chemical agents has been completely stopped, saving nearly 400,000 RMB in chemical costs annually; based on the industrial water price of 1.5 RMB/ton, saving 500,000 tons of water can save about 750,000 RMB in water costs; the power consumption is about 7kW, the annual operating time is about 4000 hours, and the electricity cost is about 20,000 RMB. The transformation project recovered all investment in about two years and greatly improved the environmental performance of the water system.

4.2. Operating Costs and Comprehensive Benefits

(1) Investment and Equipment Depreciation: The main investment items include electrochemical reactors, power control systems, and installation and commissioning. Large-scale equipment investment typically reaches the million-level. The total static investment for this project is 6.71 million, with the process system accounting for 5.58 million. Equipment lifespan primarily depends on electrode materials and structure, generally ranging from 5 to 10 years. Electrode replacement is calculated based on a 5-year lifespan, with anode replacement costs averaging 120,000/year included in depreciation. (2) Operating and Maintenance Costs: The core operating expense is electricity, which is related to water treatment volume, current density, and retention time. Annual electricity costs amount to 154,000. Maintenance expenses include electrode cleaning and replacement of wear-prone parts. The use of automatic scrapers and alternating high/low current density can reduce scaling and lower cleaning frequency. Repair and chemical (acid consumption) costs are 30,000/year. The total annual operating cost is approximately 991,000 (including electricity, repairs, depreciation, etc.). (3) Environmental and Economic Benefits: Reduced chemical usage: Directly cuts chemical costs and avoids subsequent wastewater treatment expenses caused by chemical residues. Water savings and emission reduction: Against the backdrop of rising water resource prices and stricter environmental regulations, reducing freshwater

replenishment and concentrated brine discharge offers significant economic feasibility. Improved heat exchange efficiency and extended equipment lifespan: With mitigated scaling and corrosion issues, units can operate stably under consistent conditions, reducing hidden losses from unscheduled shutdowns for maintenance. Comprehensive calculations show that the electrochemical treatment system can generate annual economic benefits exceeding 1.5 million, with a typical payback period of 2–3 years. This demonstrates the significant advantages of electrochemical technology in lowering operating costs and enhancing environmental benefits.

5. Summary

(1) Electrochemical technology, through the dual effects of anode oxidation and cathode precipitation, can actively remove hardness ions in circulating cooling water and inhibit microorganisms, significantly increasing the circulating ratio and saving replenishment water. (2) Engineering practice shows that this technology is an effective alternative to traditional chemical dosing methods. It can achieve good results in the application scenarios of medium and large thermal power units, and has the advantages of lower operating costs and less environmental impact. (3) The payback period is usually around 2-3 years. For areas with continuously rising water prices and strict environmental requirements, the actual benefits are even more significant.

Electrochemical technology possesses considerable potential for application in the treatment of circulating cooling water within thermal power plants. Future research and development endeavors should prioritize the optimization of electrode materials, aiming to decrease costs while simultaneously enhancing their operational lifespan and catalytic performance. Additional focus areas include reducing energy consumption via advancements in reactor design and power control systems, elevating the level of automation and intelligence to ensure stable and dependable system operation, and investigating the synergistic potential of combining electrochemical methods with other water treatment technologies. The applicability of this technology should be broadened to encompass a wider spectrum of water qualities and system scales. It is imperative to conduct

thorough environmental impact assessments and formulate appropriate mitigation strategies. Furthermore, the establishment of comprehensive standards and specifications is essential to foster the sustainable development of this field. Through sustained innovation, electrochemical technology is poised to contribute significantly to water conservation and emission reduction efforts in the thermal power sector.

References

- [1] He C F, Xiao N, Li J, et al. Research progress on electrochemical treatment technology of circulating cooling water. *Industrial Water Treatment*. 2022, Vol. 42 (No. 12), p. 26-33.
- [2] Cai S J, Zhao X Y, Wang Y Y. Research progress on water-saving technology of circulating cooling water. *Industrial Water Treatment*. 2009, Vol. 29 (No. 1), p. 4-8.
- [3] Hu C Y. Research progress on scale inhibition methods for circulating cooling water in thermal power plants. *Guangzhou Chemical Industry*. 2017, Vol. 45 (No. 24), p. 53-54, 90.
- [4] Xiong F, Yang H, Jin X R. Optimization of makeup water quality and system operation scheme for steel circulating water. *Industrial Water Treatment*. 2024, Vol. 44 (No. 1), p. 207-212.
- [5] Yu X B, Hu D L, Fang L, et al. Transformation scheme and economic analysis of water resource utilization and pollution prevention in a thermal power plant. *Industrial Water Treatment*. 2023, Vol. 43 (No. 10), p. 179-184.
- [6] Zhang N, Cao L, Geng C Z. Research progress on scale inhibitors for circulating water. *Modern Chemical Industry*. 2015, Vol. 35 (No. 10), p. 54-57, 59.
- [7] Su Y, Yang Y, Gu K Y, et al. Research progress on electrochemical descaling technology for circulating cooling water systems. *Industrial Water Treatment*. 2023, Vol. 43 (No. 8), p. 30-37.
- [8] Shen S Y, Feng X D, Shi G Z. Feasibility study on the application of electroadsorption technology in circulating cooling water treatment of thermal power plants. *Zhejiang Electric Power*. 2015, Vol. 34 (No. 11), p. 89-91, 99.
- [9] Wang C C, Shi J, Xiao B Y. Principle and application of electrochemical circulating water quality stabilization treatment technology. *Baosteel Technology*. 2012, Vol. 12 (No. 2), p. 63-67.
- [10] Jaouhari R, Benbachir A, Guenbour A, et al. Influence of Water Composition and Substrate on Electrochemical Scaling. *Journal of The Electrochemical Society*. 2000, Vol. 147 (No. 6), p. 2151.
- [11] Li S, Wang H F. Application of electrochemical method in cooling circulating water treatment technology. *Chemical Industry and Engineering Progress*. 2013, Vol. 32 (No. 10), p. 2514-2517.
- [12] Song G G. Research progress on chloride ion removal technology in industrial wastewater. *Energy Chemical Industry*. 2023, Vol. 44 (No. 5), p. 22-26.
- [13] Zhi D, Zhang J, Wang J, et al. Electrochemical treatments of coking wastewater and coal gasification wastewater with Ti/Ti4O7 and Ti/RuO2-IrO2 anodes. *Journal of Environmental Management*. 2020, Vol. 265, p. 110571.
- [14] Li Y N, Zhuang X Y, Li H Y, et al. Fabrication and Water Treatment Application of High Efficient PbO2 Electrode. *Key Engineering Materials*. 2017, Vol. 727, p. 821-829.
- [15] Li H Y, Yuan J Q, Li P, et al. Experimental study on reducing circulating water hardness by electrochemical water treatment technology. *Water Treatment Technology*. 2024, Vol. 50 (No. 3), p. 37-41, 47.
- [16] Hu C Z, Liu H J, Qu J H. Research progress in electrochemical water treatment technology. *Chinese Journal of Environmental Engineering*. 2018, Vol. 12 (No. 3), p. 677-696.
- [17] Guo Y, Xu Z, Guo S, et al. Selection of anode materials and optimization of operating parameters for electrochemical water descaling. *Separation and Purification Technology*. 2021, Vol. 261, p. 118304.
- [18] Dube A, Malode S J, Alshehri M A, et al. Electrochemical water treatment: Review of different approaches. *Journal of Environmental Management*. 2025, Vol. 373, p. 123911.
- [19] Liang S T, Lin H, Habteselassie M, et al. Electrochemical inactivation of bacteria with a titanium sub-oxide reactive membrane. *Water Research*. 2018, Vol. 145, p. 172-180.
- [20] Chen L, Zhao B H, Hu Y Y, et al. Pilot-scale experimental study on treatment of circulating water by electrochemical coupling method. *Thermal Power Generation*. 2025, Vol. 54 (No. 3), p. 158-166.