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Research on Key Technologies for Optimization of Water Systems and Efficient Utilization of Regenerated Water in Thermal Power Plants

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Abstract: Water is the source of life, an essential element in production, and the foundation of ecosystems. In the natural hydrological cycle, water that can be utilized by humans is referred to as water resources. Water resources form the basis for human survival and development, intimately connected to daily life, and concurrently represent a controlling factor in the ecological environment. It is well-known that the thermal power generation industry has consistently been a major consumer of water in the industrial sector, with substantial demands for water resources. Throughout the process of thermal power generation, water resources are extensively utilized for cooling, steam generation, waste heat discharge, and other processes. This large-scale utilization of water resources not only imposes pressure on local water resources but also leads to pollution of water environments and disruption of ecosystems.To address the challenges posed by the limited availability of water resources and environmental pollution, this paper explores the key technologies for optimizing water systems in thermal power plants. Through in-depth analyses of 3S water source optimization technology, ABFT biological treatment processes, recycled water utilization technology in the circulating cooling system, reclaimed water reuse technology, and the coal-fired "flue gas desulfurization" process, coupled with empirical studies of typical cases, the aim is to propose viable optimization solutions for water systems.

Keywords: Water resources; Thermal power plant; Water system optimization; Reclaimed water utilization.

1. Introduction

With the continuous development of the socio-economic landscape, thermal power plants, as primary energy suppliers meeting the ever-growing energy demands, are confronted with the increasingly scarce water resources and severe challenges of environmental pollution. Serving as significant industrial water consumers, a coal-fired power generation unit with an installed capacity of 2×300MW, utilizing a secondary circulating cooling method, can consume water up to 3.6×104 m^3/day[1,2], equivalent to the wastewater output of a medium-sized urban area. Typically, municipal sewage is centrally treated and discharged into natural water bodies, yet even when meeting national emission standards, secondary pollution issues persist. In this context, the optimization of water systems in thermal power plants becomes an urgent and crucial task.

This study aims to achieve efficient water resource utilization and reduce reliance on natural water sources by in-depth analysis and optimization of thermal power plant water systems. Simultaneously, it aims to decrease wastewater discharge, providing technical support for the sustainable development of thermal power plants. The water system in a thermal power plant is a critical component directly linked to the rational utilization of water resources and environmental protection, essential for ensuring equipment's normal operation and enhancing power generation efficiency. Through the implementation of this research, an effective balance between energy supply and water resource management in thermal power plants can be achieved, offering robust theoretical and practical support for the construction of environmentally friendly and efficiently energy-utilizing power plants.

2. Status of Research and Development Trends

(1) Current Status and Development Trend of Domestic Research

In recent decades, China has widely adopted reclaimed water utilization technologies in the thermal power generation industry. Many power plants employ advanced water circulation systems that treat wastewater for reuse in the cooling system. This initiative helps reduce the demand for freshwater resources, lower water treatment costs, and mitigate environmental impact. Domestic research has primarily focused on the application of monitoring and control systems to enhance water resource utilization efficiency within water recovery systems. Some power plants have introduced intelligent technologies for real-time monitoring and adjustment of water systems, minimizing water wastage.

In the realm of green energy, China's thermal power generation industry is gradually incorporating more environmentally friendly fuels such as natural gas and biomass energy to reduce carbon emissions. This shift also aids in decreasing the freshwater requirements of water systems[3] since these fuels demand less cooling water in the power generation process. Environmental protection policies and regulations enacted by the government encourage and standardize water system optimization, water conservation, and carbon reduction efforts within the thermal power generation industry. This has propelled more power plants to adopt green technologies, including reclaimed water utilization, to meet both domestic and international environmental standards.

(2) Overseas Research Status and Development Trend

Globally, the application of reclaimed water utilization technologies in the thermal power generation industry is expanding. Current research trends indicate a continuous increase in the application of reclaimed water utilization technologies, particularly in the ongoing improvement of key technologies such as wastewater treatment, desalination, and salt removal to ensure the quality and stability of reclaimed water. Simultaneously, novel reclaimed water technologies, such as reverse osmosis membrane technology and advanced oxidation processes, are garnering widespread attention to enhance water quality and reduce treatment costs.

International research emphasizes the optimization of water recovery systems through real-time monitoring and control systems to adjust water usage and minimize waste. Attention is also directed towards the design of water systems and equipment improvements to enhance water resource utilization efficiency. In the realm of intelligent and data-driven water system management, there is an increasing focus on applying sensors and automation control systems to thermal power generation water systems globally. This includes real-time data analysis to improve the efficiency of water systems, better cope with emergencies, reduce water wastage, and lower carbon emissions[4]. Cross-border collaboration and knowledge sharing are recognized as key factors driving water system optimization and water conservation efforts. Internationally, cooperation between research institutions, governments, and industry organizations facilitates the sharing of best practices and innovative technologies, accelerating technology adoption and dissemination, and reducing the global thermal power generation industry's dependence on water resources.

3. Water System Optimization: Key Technology Analysis

(1) 3S Water Source Optimization Technology

The 3S water source optimization technology plays a pivotal role in the optimization of water systems in the thermal power generation industry. This technology integrates remote sensing, Global Positioning System (GPS), and Geographic Information System (GIS) technologies to provide scientifically efficient solutions for water source selection and optimization. The use of GPS receivers ensures precise positioning of water intake points, providing a reliable foundation for subsequent water resource management and data analysis. Remote sensing technology utilizes satellite sensors and aerial photography to gather surface features and topographic data of the surrounding area[5]. This data is crucial for understanding environmental conditions at water intake points, water source distribution, and predicting future water resource trends. The application of Geographic Information System (GIS) visually presents the results of water source selection in graphical and chart formats. This visualization aids decision-makers in comprehending the complexity of water systems, allowing them to intuitively understand the distribution and related information of water sources. The application of 3S water source optimization technology provides comprehensive and reliable technical support for thermal power plants in the water intake process. By fully leveraging modern information technology, it ensures the efficient utilization of reclaimed water sources, laying a solid technological foundation for the sustainable development and optimization of water systems in thermal power plants.

(2) Biological Treatment Processes

Biological treatment processes efficiently degrade organic pollutants, nitrogen, phosphorus, and other contaminants in wastewater using advanced biological treatment methods such as activated sludge processes and anaerobic ammonia oxidation processes. This technology transforms pollutants into clean reclaimed water resources. It offers advantages such as low energy consumption, wide applicability, and environmental friendliness. Common biological treatment processes include Constructed Wetlands, Biological Gasification Technology, and Aerated Biofilm and Fluidized Bed Technology (ABFT)[6]. Constructed wetlands effectively purify wastewater treatment plant effluent by constructing wetland systems, providing clean reclaimed water sources for thermal power plants. Biological gasification technology converts organic waste into combustible gas, serving as fuel for the combustion process in thermal power plants, achieving both environmental and economic benefits. Aerated biofilm and fluidized bed technology efficiently treat high-concentration organic wastewater, degrading organic substances in wastewater to produce reclaimed water meeting the water intake standards for thermal power plants, which can be reused in the circulating cooling system. In the application of biological treatment technologies, various reactors ensure uniform microbial distribution, effectively degrading organic substances and improving reclaimed water quality. In summary, biological treatment processes provide scientifically feasible technical support for the water intake process in the thermal power generation industry. By selecting suitable biological treatment processes and monitoring and control measures, the efficient utilization of reclaimed water is achieved, offering viable solutions for water system optimization.

(3) Recycled Water Utilization in Circulating Cooling Systems

Recycled water utilization technology in circulating cooling systems involves treating wastewater generated in the cooling system and recycling it for use in the production process. This achieves the efficient reuse of water resources, providing an effective means for the sustainable development and water resource management of thermal power plants. Initially, through advanced treatment of cooling water, the technology ensures that the quality of recycled water meets production standards. Subsequently, the treated recycled water is reused in the circulating cooling system, alleviating pressure on natural water sources and reducing the adverse environmental impact of wastewater discharge. The advantages of this technology not only contribute to water resource conservation but also enhance the efficiency of the cooling system. By maintaining the appropriate temperature of recycled water, it helps stabilize the operation of the cooling system, thereby improving the energy efficiency of thermal power plants[7]. In conclusion, recycled water utilization technology in circulating cooling systems is a practical and efficient key technology in the optimization of water systems in the thermal power generation industry. Through the combination of scientific management and advanced technological methods, it maximizes the reuse of water resources, laying a solid foundation for the sustainable development of thermal power plants.

(4) Reclaimed Water Reuse Technology

Reclaimed water refers to water that, after preliminary treatment, can be reused without the need for extensive purification. Typically originating from industrial, agricultural, or urban water processes, this type of water undergoes initial treatment to remove some pollutants but does not fully meet the standards for drinking water or other high-purity water. The reuse of reclaimed water is considered an effective water resource management method, helping alleviate pressure on freshwater resources, improve water resource utilization efficiency, and reduce environmental impact. Reclaimed water reuse technology holds significant importance in the optimization of water systems in thermal power plants.

This technology encompasses three main stages: reclaimed water recovery, reclaimed water treatment, and reclaimed water reuse. It involves the centralized collection and thorough treatment of generated reclaimed water to achieve sustainable utilization and conservation of water resources. Initially, in the reclaimed water recovery stage, equipment such as sedimentation tanks and filters are used for preliminary treatment. Subsequently, through reclaimed water treatment processes employing appropriate methods, reclaimed water undergoes deep treatment to ensure its quality meets reuse standards[8]. Finally, in the reclaimed water reuse stage, the treated reclaimed water is applied to production processes, such as boiler makeup water and cooling water. The application of reclaimed water reuse technology brings significant economic and environmental benefits. By reducing dependence on external freshwater sources, thermal power plants lower water costs and enhance water resource utilization efficiency. Simultaneously, it reduces water pollution, alleviates water pressure, and aligns with the principles of sustainable development.

(5) Coal-Fired "Flue Gas Desulfurization" Process

In recent years, with increasingly stringent environmental standards, many power plants have undertaken large-scale flue gas ultra-low emission transformations. During the desulfurization process, desulfurization wastewater is inevitably generated, presenting challenges due to its complex composition, significant water quality variations, and potential harm, making it a focal point of pollution control in coal-fired power plants[9]. The coal-fired "flue gas desulfurization" process is a novel method aimed at achieving zero discharge of desulfurization wastewater. The principle involves atomizing an alkaline solution into the flue duct before the dust collector, removing acidic gases such as HCl from the flue gas, and solidifying them into fly ash. This dramatically reduces the discharge of desulfurization wastewater. The reduced desulfurization wastewater can further be sprayed back into the flue duct, achieving zero-flow discharge of desulfurization wastewater[10].

This process generally includes wet desulfurization and dry desulfurization as the main methods. Wet desulfurization involves introducing suitable desulfurization agents, such as ammonia solution or sodium hydroxide solution, to react with chlorine in the flue gas, generating water-soluble salts to achieve the desired chlorine removal effect. Dry desulfurization utilizes adsorbents or chemical reactions to adsorb and convert chlorine in the flue gas. From a water system perspective, the implementation of coal-fired flue gas desulfurization technology can reduce the direct discharge of chloride ions into water bodies, effectively protecting water quality. Moreover, a well-designed flue gas treatment system can recover removed chlorides, promoting resource reuse and further reducing environmental burdens.

4. Case Study Analysis

In recent years, Zhejiang Zheneng Changxing Power Generation Co., Ltd. (hereinafter referred to as "Zheneng Changxing") in Changxing County, Huzhou City, Zhejiang Province, has actively implemented the production and operation philosophy of "Saving Water is Emission Reduction." Innovatively achieving "zero surface water intake" and "zero wastewater discharge," it has become the first domestic coal-fired power plant with "double zero" emissions. Therefore, this study takes Zheneng Changxing as a typical case, analyzing its water system optimization key technologies from the aspects of water intake, water usage, and wastewater discharge. The goal is to summarize effective technical support for the construction of a recycled water utilization support system in power plants.

(1) Water Intake Analysis

Zheneng Changxing introduces treated wastewater from the sewage treatment plant, implementing projects such as the transmission network and pump station to deliver the pre-treated wastewater to the power plant for recycling. In this process, the main pollutants in the wastewater are NH_3-N, while other control indicators such as COD_{cr}, BOD_5, and phosphates are not significantly higher than the water discharge standards. Additionally, considering the copper material of the cooling water heat exchanger, the NH_3-N index in the recycled water should be less than 1.0mg/L. Therefore, Zheneng Changxing primarily focuses on removing NH_3-N from the incoming wastewater, requiring a NH_3-N total removal rate of 93.4%, which is a demanding standard.For this reason, Zheneng Changxing adopts the Aerated Biofilm and Fluidized Bed Technology (ABFT) in the water intake process. Through the combined action of the ABFT process and counterflow sedimentation tanks, the wastewater from the sewage treatment plant undergoes deep treatment using a two-layer superimposed structure (refer to Figure 1).

Zheneng Changxing employs the ABFT process by introducing a highly efficient microbial carrier, constituting 40%-60% of the effective volume of the aeration tank within the ABFT reactor. Specialized microorganisms adhere and fix themselves in abundance onto this carrier. Across various levels of ABFT reactors, different strains of specific advantageous bacteria are cultivated to enhance the degradation efficiency of target pollutants. The carrier's biomass growth can reach up to 10-18g/L, and the binding of live microorganisms to the carrier utilizes immobilization technology based on covalent bonding. This robust bonding ensures a firm attachment, preventing detachment, and the high biomass load guarantees the efficiency and stability of pollutant removal in ABFT reactors[11]. Throughout the operational process, each carrier's internal environment maintains well-balanced aerobic, anaerobic, and anoxic conditions, leading to the formation of numerous miniature nitrification-denitrification reactors. Consequently, simultaneous occurrences of ammonia oxidation, nitrification, and denitrification within the same reactor robustly ensure the effective removal of ammonia nitrogen[12].

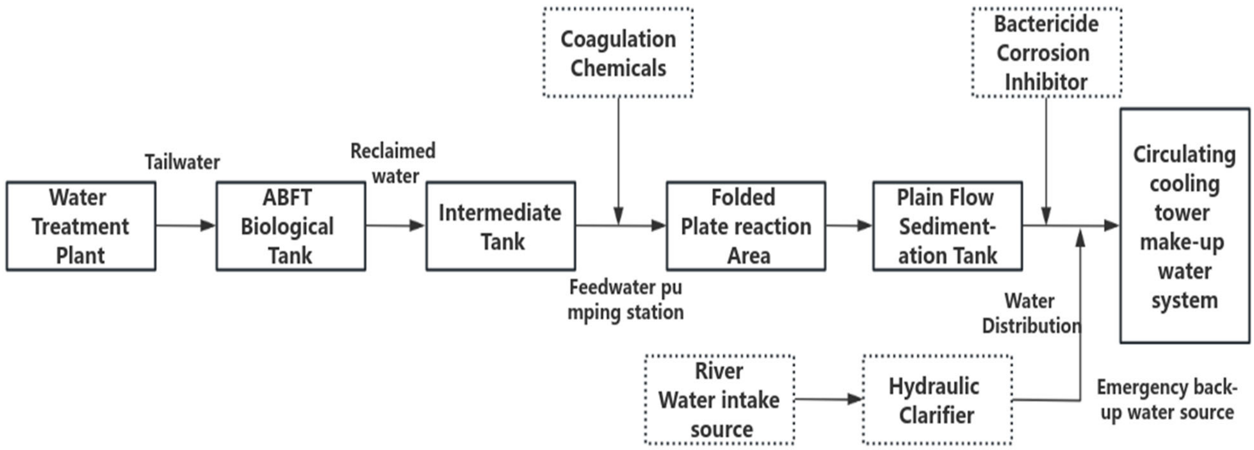

Figure 1. Zheneng Changxing Wastewater Deep Treatment Process

(Note: In the first phase of the power plant, river water intake remains unchanged, serving as supplementary water for the plant's living and chemical water facilities. In the second phase, it also serves as an emergency water source for deep treatment processes. When the incoming water quality deteriorates or water quantity is insufficient, it can be switched to ensure the safety of the circulating cooling tower water.)

(2) Water Usage Analysis

Zheneng Changxing's power generation process comprises five major systems: the fuel system, combustion system, steam-water system, electrical system, and control system. Due to the close correlation between the steam-water system and the use of reclaimed water, this section focuses on the water system optimization within the steam-water system at Zheneng Changxing.

The steam-water system at Zheneng Changxing (refer to Figure 2) primarily consists of devices such as the deaerator, high-pressure heater, boiler, steam turbine, condenser, and low-pressure heater. This includes processes such as steam-water circulation, cooling water circulation, and chemical water treatment technologies.

In the water intake stage, Zheneng Changxing utilizes reclaimed water after thorough treatment. This reclaimed water is mainly employed in the following aspects of the steam-water system:

a. Water usage in the cooling tower

According to Zheneng Changxing's project verification, the ABFT (Aerated Biofilm and Fluidized Bed Technology) process exhibits a significant purification effect on water quality, particularly in the removal of NH_3-N and COD_{cr}. The control standards for this process are as follows: $COD_{Cr} \leq 20mg/L$; $BOD_5 \leq 5mg/L$; $SS \leq 15mg/L$; Phosphate $\leq 1mg/L$; NH_3-N $< 1mg/L$. These water quality indicators meet the control requirements for the power plant's circulating water, ensuring the safety of the circulating water system. Therefore, Zheneng Changxing primarily utilizes the reclaimed water treated by the ABFT process for the cooling tower, with a designed scale of up to 60,000 m^3/day. This ensures effective condensation of steam in the steam turbine,

maintaining the normal operation of the steam-water system.

b. Boiler feedwater process

In the steam-water system, water treatment for the boiler includes processes such as feedwater treatment, condensate treatment, water deoxygenation, water ammonia treatment, and internal boiler chemical treatment. In this stage, Zheneng Changxing uses reclaimed water after thorough treatment. This water undergoes pressure-driven membrane filtration using ultrafiltration (UF) technology to remove suspended solids and solutes. It is further treated through resin exchange to produce desalinated water, which serves as feedwater for the boiler, supporting the steam-water circulation in the power plant units. The treatment of condensate water is crucial in the boiler feedwater process, as the circulation system may lead to leaks of circulating water in the steam turbine generator's condenser, resulting in contamination and corrosion of system materials[13]. In this regard, Zheneng Changxing uses reclaimed water for the cyclic cooling of condensate water, achieving refined treatment effects. Moreover, reclaimed water is also applicable in processes such as chemical dosing for the boiler's internal treatment and water deoxygenation for feedwater.

(3) Drainage Analysis

Zheneng Changxing has undertaken an upgraded transformation of its existing industrial wastewater treatment system in the drainage process, establishing itself as a pioneer within the Zheneng Group and initiating exploration into "Zero Wastewater Discharge." Through a method involving classified collection, quality-based treatment, and comprehensive processing, the power plant's drainage system has been optimized, enhancing the overall utilization of water resources.

a. Analysis of Conventional Wastewater Reuse

The domestic sewage system is equipped with an independent network for domestic wastewater. After the collection of domestic sewage, it undergoes quality and quantity adjustments in a regulating pool before being elevated to the BioComb mobile sewage treatment unit for biochemical treatment[14]. Upon meeting the required standards, the treated water is reused in the central water system as supplemental water for circulating cooling. This process results in an annual reduction of approximately 5.4 tons of COD emissions.

The sludge water system involves directing sludge water (from coal and combustion engines) to a regulating pool, followed by the use of a lift pump to facilitate initial natural sedimentation in a settling tank. The clarified liquid is then reused in a clarification tank, while the sludge water undergoes centrifuge treatment. The clarified water is reused in the clarification tank, and the sludge is transported to the coal-fired coupling project's sludge drying system. This approach allows for the reuse of water, with an increase in recycled water of about 200,000 m³/year and a decrease in suspended solids emissions of approximately 60 tons/year.

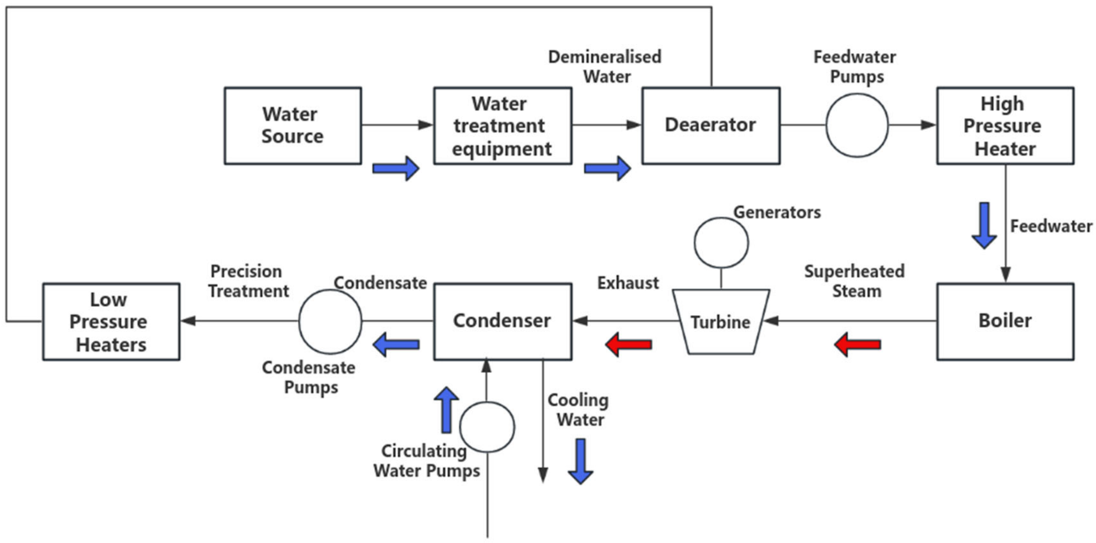

Figure 2. Water Usage Process in Zheneng Changxing Steam-Water System

(Note: Red arrows indicate the direction of gas flow; blue arrows indicate the direction of water flow)

Chemical water treatment wastewater comprises regenerated wastewater (from coal engine treatment, coal engine precision treatment, and combustion engine treatment), equipment backwash water, RO concentrate water (from coal and combustion engines), ammonia area wastewater, and unit drainage (from coal and combustion engines). Regenerated wastewater is collected and centrally treated in a wastewater pool, undergoes neutralization, and is discharged into the central water system for further treatment. It serves as supplemental water for circulating cooling. Backwash water from equipment and unit drainage are reintroduced into the water production system after coagulation and clarification. RO concentrate water is reused in the cooling tower as makeup water for circulating water. Ammonia area wastewater, after treatment in the central water ABFT system, is used as supplemental water for circulating cooling. This results in an increase in recycled water of about 1 million tons/year and a reduction in ammonia nitrogen emissions of approximately 80 tons/year.

b. Analysis of Desulfurization Wastewater Reuse

Desulfurization wastewater, due to its complex composition, significant variability in water quality, and potential harm, has been a focal point in the pollution control efforts of coal-fired power plants. Zheneng Changxing has adopted the more convenient "spray drying process" to treat desulfurization wastewater, constructing the "bypass flue gas spray drying desulfurization wastewater system." In this system, desulfurization wastewater is atomized using a sprayer, and the wastewater evaporates within the spray drying tower using boiler flue gas as a heat source. The water vapor enters the flue gas, and salts in the wastewater dry out, with the dried salts extracted at the bottom of the tower[15]. This approach achieves zero discharge of desulfurization wastewater, utilizing the heat energy of the boiler flue gas without requiring additional steam sources[16]. According to statistics, this system can process 3 tons of desulfurization wastewater per hour, cumulatively reducing solid waste emissions by approximately 600 tons/year and COD emissions by about 8.25 tons/year.

5. Summarize

With the ongoing progress of the current economic and social high-quality development, the imperative to transition water usage in thermal power plants towards conservation and intensification is becoming more pronounced. This study conducts an in-depth analysis of key technologies for optimizing water systems in thermal power plants, emphasizing the utilization of reclaimed water. This includes 3S water source optimization technology, biological treatment processes, recycled water utilization in cooling systems, water reuse, and the coal-fired "flue gas desulfurization" process. Taking Zheneng Changxing Thermal Power Plant in Changxing County, Huzhou City, Zhejiang Province, as a typical case, the study effectively demonstrates the critical role of these technologies in improving water resource utilization efficiency, reducing reliance on natural water sources, and mitigating wastewater discharge.

In the future, both domestic and international enterprises in the thermal power generation industry can refer to the technologies outlined in this research. By aligning with specific organizational needs, adopting advanced treatment techniques, and implementing optimized water system solutions, the realization of efficient, environmentally friendly, and sustainable development of water systems in thermal power plants becomes achievable.

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