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Study on Process Optimization and Energy Efficiency Improvement in Upgrading and Renovation of Sewage Treatment Plant

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Abstract: With the increasingly stringent environmental protection requirements and the advancement of the dual-carbon goal, it is urgent to upgrade the standard of sewage treatment plants. This study focuses on the two cores of process optimization and energy efficiency improvement. In terms of process optimization, technologies such as biological treatment enhancement, advanced treatment upgrade, nitrogen and phosphorus removal efficiency improvement, and sludge treatment and disposal optimization are discussed; energy efficiency improvement covers aeration system optimization, precise control and intelligent operation and maintenance, energy recovery and utilization, equipment energy efficiency upgrade, and the construction of the whole process energy efficiency management system. Through the comprehensive application of these technologies, the aim is to achieve efficient, low consumption, stable operation of sewage treatment plants, meet new emission standards, reduce carbon emissions, provide theoretical and practical reference for the sustainable development of the industry, and promote the transformation and upgrading of sewage treatment plants to green and intelligent directions.

Keywords: sewage treatment plant; upgrading reconstruction; process optimization; energy efficiency improvement

Introduction

At a time when environmental protection is receiving more and more attention, water resource protection and rational utilization have become key issues. As an important line of defense to protect the water environment, the operation effect of sewage treatment plants directly affects water ecological security. However, with the continuous improvement of emission standards and the proposal of

dual-carbon targets, existing sewage treatment plants are facing many challenges. In this context, it has become an inevitable choice to upgrade the standard of sewage treatment plants, optimize the treatment process and improve the level of energy efficiency. This study deeply explores the process optimization and energy efficiency improvement technologies in the upgrading of sewage treatment plants, and provides strong support for promoting the technological progress



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and sustainable development of the industry.

1. Demand and technical status of wastewater treatment plant renovation

1.1 Emission standard improvement Requirements for standard upgrading and transformation

In recent years, the national and local water pollutant discharge standards have been continuously tightened, forming rigid constraints on the transformation of sewage treatment plants. The quasi-Class IV standard for surface water has been gradually promoted in key watersheds, requiring major indicators such as chemical oxygen demand, ammonia nitrogen, and total phosphorus to meet or be close to the Class IV water quality standards for surface water. Compared with the traditional Class A standard, the new standard has stricter requirements on total nitrogen and total phosphorus, and the limits of some indicators have been narrowed by more than 50%. Some sensitive areas have also proposed stricter special emission limits. Standard upgrading brings multiple technical challenges: conventional secondary treatment is difficult to stably meet the standards, and advanced treatment units need to be added; the efficiency of nitrogen and phosphorus removal is required to be improved, and the original process capacity is insufficient; the nitrification effect is difficult to guarantee under low temperature conditions in winter; the lack of carbon source affects the At the same time, the improvement of standards also brings secondary problems such as increased sludge production and increased consumption of chemicals, which need to be dealt with in the transformation. The trend of continuous tightening of emission standards will continue, and the transformation design needs to reserve space for further improvement in the future.

1.2 Energy efficiency requirements under the dual-carbon target

The "double carbon" goal clearly requires all industries to reduce carbon emissions. As a high energy consumption field, the sewage treatment industry mainly focuses on aeration, lifting, sludge treatment and other links. The power consumption per unit of treated water remains high, and the carbon emission intensity is high. It has become a key area of low-carbon development. Under the double carbon goal, the upgrading of sewage treatment plants should not only achieve the improvement of water output standards,

but also focus on energy efficiency improvement and reduce operating energy consumption and carbon emissions. It is required to reduce traditional energy consumption, promote the utilization of renewable energy, and build a low-carbon operation mode through technological innovation, equipment upgrading, and management optimization.^[1] At the same time, energy efficiency improvement can also reduce the operating costs of wastewater treatment plants, enhance the sustainable development capacity of the industry, and achieve the synergy of environmental benefits, economic benefits, and social benefits. This is also one of the core directions for the current transformation of wastewater treatment plants.

1.3 Current status of existing wastewater treatment plant technology

At present, the technical level of existing sewage treatment plants in our country is uneven, most of the old water plants have been built for a long time, the process is backward and the equipment is aging, and there are mainly three problems: first, the biological treatment process efficiency is low, the impact resistance of the conventional activated sludge method is weak, the effect of nitrogen and phosphorus removal is unstable, and it is difficult to adapt to the fluctuation of water quality and new discharge standards; second, the application of deep treatment technology is insufficient, some water plants are not equipped with perfect deep treatment units, the water quality is difficult to further improve, and the utilization rate of water resources recycling is low; third, the level of energy efficiency management is backward, the high-energy equipment is not upgraded in time, the lack of scientific energy efficiency monitoring and control system, and the energy waste is serious. At the same time, the sludge treatment and disposal process is not perfect, which not only increases energy consumption In addition, the traditional operation and maintenance model of some water plants has a low level of intelligence, which further restricts the improvement of treatment efficiency and energy efficiency.

2. Wastewater treatment plant process optimization technology

2.1 Biological treatment enhancement technology

Biological treatment is the core link of wastewater treatment, and process strengthening mainly focuses

on improving microbial activity and optimizing the reaction environment. Common technologies include improved activated sludge process, biofilm method and activated sludge method composite process, etc. The improved A²O process enhances denitrification and phosphorus removal effects by optimizing the structure and operating parameters of the tank, improves pollutant removal efficiency, and adapts to the needs of high-nitrogen phosphorus wastewater treatment. The biofilm composite process combines biofilm and activated sludge, which combines both advantages to enhance the impact resistance of the system, reduce sludge production, and reduce subsequent treatment pressure. At the same time, by adding high-efficiency microbial inoculants, optimizing the aeration method and stirring intensity, the growth environment of microorganisms can be improved, the ability of microorganisms to degrade pollutants can be improved, and the efficiency of biological treatment can be improved, which lays the foundation for the effluent to meet the standards without the need for large-scale new structures. The cost of transformation is relatively low.

2.2 Deep processing upgrade technology

Deep treatment is the key to achieve the standard of effluent. It is mainly used to remove trace pollutants, suspended solids and nitrogen and phosphorus left after biological treatment. Common technologies include ultrafiltration, advanced oxidation, activated carbon adsorption, etc. Ultrafiltration technology can effectively remove suspended solids, colloids and some microorganisms in water, improve the transparency of the effluent, and as the core unit of deep treatment, it can be combined with reverse osmosis to achieve water resource reuse. Advanced oxidation technology (such as ozone oxidation, Fenton oxidation) can efficiently degrade non-biodegradable organic matter and solve the problem of pollutants that are difficult to treat by traditional processes. Activated carbon adsorption can remove trace organic matter, odor and color in water, further improving the quality of the effluent. The upgrade of advanced treatment technology needs to be combined with the actual water discharge requirements of the water plant, and the process combination should be rationally matched to ensure that the discharge standard is met, while taking into account the economy and the convenience of operation and maintenance, and promoting the recycling of water resources^[2].

2.3 Efficiency-enhancing technology for nitrogen and phosphorus removal

Aiming at the problem of poor nitrogen and phosphorus removal effect in existing wastewater treatment plants, the synergistic technology mainly focuses on process parameter optimization and auxiliary means strengthening. In terms of nitrogen removal, a segmented nitrification and denitrification process is adopted to optimize parameters such as sludge age and dissolved oxygen concentration, improve nitrification and denitrification efficiency, and reduce total nitrogen emissions; short-range nitrification and denitrification technology is introduced to shorten the reaction process and reduce energy consumption. In recent years, the AOA (anaerobic-anoxic-aerobic) process has attracted attention due to its high efficiency in simultaneous nitrogen and phosphorus removal. It enhances the enrichment of denitrifying phosphorus removal bacteria (DPB) by alternating anoxic/aerobic environments to achieve "one-carbon dual-use". It can reduce the demand for carbon sources and improve the removal rate of total nitrogen and total phosphorus. It is especially suitable for the efficient treatment of low-carbon source urban wastewater. In terms of phosphorus removal, optimize the chemical phosphorus removal agent dosing plan, adopt precise dosing technology, and dynamically adjust the dosing amount according to the phosphorus concentration of the influent water to reduce the waste of the agent and secondary pollution; combine the biological phosphorus removal process to strengthen the enrichment and phosphorus release process of phosphorus-accumulating bacteria, and improve the phosphorus removal effect. By optimizing the regulation of influent water quality and improving the mixing effect of the reaction tank, the synergistic effect of nitrogen and phosphorus removal is further strengthened to ensure that the nitrogen and phosphorus index of the effluent is stable and up to standard.

2.4 Optimization of sludge treatment and disposal

Sludge treatment and disposal is an important part of the transformation of sewage treatment plants. The optimization goal is to achieve sludge reduction, resource utilization and harmlessness. Commonly used optimization technologies include sludge anaerobic digestion, aerobic fermentation, dehydration and drying, etc. Sludge anaerobic digestion can convert the organic matter in the sludge into biogas, realize

energy recovery and utilization, and reduce sludge production at the same time; aerobic fermentation can convert sludge into organic fertilizer to achieve resource utilization. It is suitable for small and medium-sized sewage treatment plants. Dehydration and drying technology combines mechanical dehydration with thermal drying to reduce the moisture content of sludge, facilitate subsequent disposal and transportation, and reduce energy consumption and environmental protection hazards during sludge disposal. Optimize the sludge treatment process, realize the coordinated operation of sludge and the main process, reduce the impact of sludge treatment on the overall energy consumption, and strengthen the environmental protection control of the sludge disposal process to avoid secondary pollution.

3. Energy efficiency improvement technologies for wastewater treatment plants

3.1 Aeration system optimization

The aeration system is the unit with the highest energy consumption in the sewage treatment plant, accounting for 50% -70% of the total power consumption. It is crucial to optimize its energy efficiency. First, the selection of high-efficiency aeration equipment can greatly reduce energy consumption. For example, the microporous aerator is better than the perforated pipe and the coarse bubble aerator due to its high oxygen mass transfer efficiency. It should be used first when renovating. Ceramic membrane and rubber membrane aerators have their own advantages and need to be selected in combination with water quality and maintenance conditions. Secondly, optimizing the arrangement of the aerator can balance the distribution of dissolved oxygen in the tank and avoid local over-exposure or insufficient. The cyclone aerator is suitable for oxidation ditch and has both the functions of pushing and oxygenating. Precise aeration control adjusts the aeration volume in real time by online monitoring parameters such as ammonia nitrogen, dissolved oxygen and flow rate. Common strategies include dissolved oxygen fixed value control, ammonia nitrogen cascade control and feed-feedback composite control; intelligence system can predict the change of water inlet load and adjust the fan operation in advance^[3]. Adopt frequency conversion adjustment instead of valve control to ensure that the working point is in

the high-efficiency area. Magnetic suspension and air suspension bearing blowers become the first choice for upgrading due to high efficiency and low noise; When multiple typhoons are connected in parallel, the combination needs to be optimized to maximize the overall efficiency. Zoning control divides the biological pool into multiple independent areas, and adjusts the aeration volume on demand to avoid the waste of global unified control. Daily maintenance requires regular cleaning or replacement of the aerator to prevent blockage from affecting the efficiency.

3.2 Precise control and intelligent operation and maintenance

Precise control and intelligent operation and maintenance are important means to improve energy efficiency. Through the introduction of digital and intelligent technology, accurate control of the whole process of sewage treatment can be realized. Build an intelligent monitoring system to monitor data such as influent water quality, water volume, reaction tank parameters, and equipment operating status in real time. Optimize operating parameters through big data analytics to achieve precise regulation of process operation. Adopt an intelligent control system to realize automatic control of aeration, lifting, and drug dosing, reducing human operation errors and improving operation efficiency. Build an intelligent operation and maintenance platform to realize functions such as equipment failure warning, remote monitoring, and operation and maintenance scheduling. Reduce equipment downtime, reduce operation and maintenance costs, and further improve overall energy efficiency through fine management. Realize intelligent and efficient operation of sewage treatment plants.

3.3 Energy recovery and utilization

Energy recovery and utilization can promote the transformation of sewage plants from energy consumers to energy producers. It is necessary to coordinate technical feasibility, economy and policy support to gradually increase the energy self-sufficiency rate. Anaerobic digestion of sludge to produce marsh is a mature technology. High-concentration sludge is digested at medium or high temperature to produce biogas (methane accounts for 50% to 70%), which can be used for power generation, heat production and purification into biological natural gas. The combined

heat and power system can recover waste heat for digestion tank heating to improve comprehensive energy efficiency. The water source heat pump extracts heat energy from the water and uses it for heating and cooling in the factory area. The energy efficiency ratio is 4 to 5, and the energy saving effect is significant. Photovoltaic power generation uses the roof, pool surface and other spaces of the factory area to build power stations, and flexible components are adapted to irregular areas; hydropower generation uses the difference in the elevation of the water inlet and outlet to install Through cogeneration optimization, energy cascade utilization, energy storage systems, and regional energy collaboration, we can solve the problem of matching energy supply and demand, maximize energy efficiency, and promote low-carbon and efficient operation of wastewater treatment plants.

3.4 Equipment energy efficiency upgrade

Equipment energy efficiency upgrade is the basis for energy efficiency improvement. Upgrade and transform high-energy-consuming equipment in sewage treatment plants to reduce the energy consumption of equipment operation. Replace core high-energy-consuming equipment such as lifting pumps, mixing equipment, and sludge dehydration equipment with high-efficiency and energy-saving models to improve equipment operation efficiency and reduce energy consumption; use frequency conversion control technology to dynamically adjust the speed according to the operating load of the equipment to avoid no-load or overload operation of the equipment, and achieve energy saving and consumption reduction. At the same time, strengthen the daily maintenance and maintenance of equipment, regularly repair and lubricate the equipment, reduce the incidence of equipment failure, prolong the service life of the equipment, and ensure that the equipment is stable in a high-efficiency and energy-saving state for a long time^[4]. Eliminate old and inefficient equipment, optimize equipment configuration, and achieve precise matching between equipment operation and process requirements, and further enhance overall energy efficiency.

3.5 Whole process energy efficiency management system

The energy efficiency management of the whole process is the institutional guarantee for the continuous

improvement of energy efficiency of the sewage plant. The core is to integrate the concept of energy conservation into daily operation to form a virtuous circle of continuous improvement. First, establish an energy consumption baseline, and determine the reasonable energy consumption of each unit based on historical data or similar benchmarks as the basis for assessment; build a three-level energy consumption online monitoring system for the whole plant, unit and main equipment, and connect the data to the central control system to realize real-time control of energy consumption dynamics. At the same time, build an energy efficiency index system, covering comprehensive power consumption, unit power consumption, drug consumption, etc., and correlate water volume and water quality loads; identify gaps and problems through energy efficiency benchmarking and energy efficiency audits, and rely on the industry's energy efficiency leader system to clarify the direction of improvement. Regularly carry out comprehensive energy efficiency diagnoses Linking energy efficiency indicators into performance appraisals and salaries to stimulate energy-saving motivation for all employees; promoting best practices through operation optimization systems, energy-saving technical transformation project management, and introducing contract energy management can reduce the pressure on renovation funds and ensure long-term sustainability of energy-saving effects.

Conclusion

The upgrading of sewage treatment plants is an inevitable choice to adapt to the improvement of emission standards and the goal of "double carbon". Process optimization and energy efficiency improvement are the core contents of the transformation. Together, the two can achieve multiple goals of water discharge standards, energy consumption reduction and cost savings. In the future, it is necessary to combine the development trend of the industry to further promote technological innovation and intelligent upgrading, improve the whole process energy efficiency management system, and provide stronger support for water environment governance and the realization of the "double carbon" goal.

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