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Exploration of high efficiency and low energy consumption industrial water treatment process

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Abstract: With the acceleration of industrialization, the problem of water resource pollution is becoming more and more serious, and the development of industrial water treatment technology is particularly important. This review will focus on the main processes of industrial water treatment, including physical treatment methods, chemical treatment methods, biological treatment methods, and combined processes. The diversity of technologies for industrial water treatment provides effective solutions for different types of wastewater. Optimization of combined processes and improvement of treatment efficiency will be the main directions in future research.

Industry is the core industry of our economy, and our gross industrial product ranks first in the world[1]. With the rapid expansion of population growth and urbanization, due to resource reduction and overdevelopment, water pollution, and insufficient maintenance of infrastructure, by 2050, urban water demand will increase by 80%, and 5 billion people will face severe water shortage[2]. China adheres to the priority of water conservation, strict control of the total amount of water consumption, improve efficiency; water to determine demand, rationally determine the structure and scale of development, to ensure harmony between man and nature[3]. Therefore, saving industrial water, recycling industrial water is particularly important for water resource management.

1. Current status of industrial wastewater

China is a large industrial country, and industrial wastewater is generated in many fields, such as iron and steel smelting, metal plating, agro-food processing, textile industry, and paper making (see Figure 1). The research and development of low-cost, low-energy, high-efficiency industrial wastewater treatment technology in line with the concept of green environmental protection is currently the top priority of water resources management[4-7].

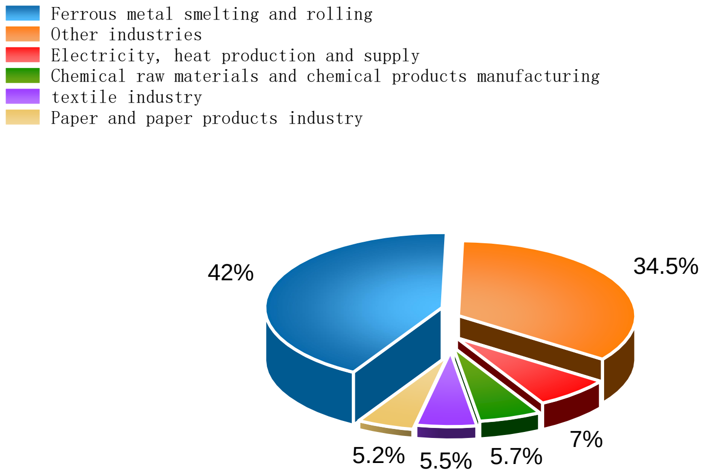

Figure 1 Wastewater Treatment Volume of Individual Industrial Sectors in 2023

2. Industrial wastewater treatment technologies

2.1 Physical treatments

Membrane filtration technology is an efficient water treatment method, which mainly depends on the design and preparation of membrane materials. At present, membrane materials are mainly divided into organic and inorganic membranes, of which organic membranes in practical applications have short service life, cleaning difficulties and poor stability. For this reason, more and more researchers are turning to inorganic membranes, especially ceramic membranes, because of their excellent thermal stability, mechanical strength, chemical resistance and recycling performance, which can realize the double effect of rapid and precision filtration, the application of ceramic membranes in the field of water treatment is growing rapidly, especially in wastewater treatment has been widely used[8]. Zhang et al.[9] loaded TiO_2/MnO_2 catalyst onto the surface of ceramic membrane by simple spraying-low temperature sintering, and found that its catalytic O_3 oxidative degradation of RhB was optimal at 12 layers of spraying, with a removal rate of up to 100%.Mouiya et al.[10] mixed pure Moroccan natural mineral, red clay, and natural phosphates, and prepared flat plate ceramic micro filtration membranes and found to remove up to 99.98% of turbidity from workshop wastewater. Hu Xuebing et al.[11] used nano ZnO, TiO_2, SnO_2 grains and graphene oxide modification, which can significantly improve the membrane oil retention rate.Chen et al.[12] combined nanotechnology with traditional ceramic membranes and implanted carbon nanotubes into the membrane pores using vapor deposition, and found that the retention rate of emulsion particles could reach 100%.

2.2 Chemical treatments

Ozone oxidation is a green wastewater treatment technology with rapid reaction, simple process and no secondary pollution, which can remove some toxic substances and heavy metal ions from wastewater. Ozonation is used to enhance the biodegradability of wastewater by generating low molecular weight and biodegradable intermediates to improve the treatment efficiency[13]. However, ozonation alone has low ozone utilization and high energy consumption[14], therefore, since ozonation has been put into use, scholars from various countries have discovered and applied more and more catalysts and catalytic processes to ozone-catalyzed oxidation treatment. Deng et al.[15-16] prepared an iron-oxide doped granular activated carbon catalyst for the catalytic ozonation of microbubbles, and found that the phenolic compound removal was effectively increased compared to the ozonation alone. The removal rate of phenolic compounds was effectively increased.Li et al.[17] used iron filings as a catalyst and found that the catalytic effect of the iron filings-based catalyst was superior to that of the commonly used powder catalyst. It was experimentally determined that the hydroxyl radical was an effective oxidizing agent to catalyze the ozonation process.In addition to that, the application of the iron filings-based catalyst provides a feasible method for the resourceful use of the waste iron filings.

The main principle of Fenton oxidation is to generate hydroxyl radicals through the reaction between hydrogen peroxide and ferrous salts in an acidic environment, and the strong oxidizing property of hydroxyl radicals can rapidly degrade organic matter, so as to achieve the purpose of removing pollutants[18]. However, the Fenton process has problems such as limited pH, low reaction efficiency, and secondary pollution, so the Fenton process can be combined with other processes to overcome the above shortcomings and realize the large-scale application of the Fenton process [19].Omar et al.[20] used two methods, Fenton and electro-Fenton, for the pretreatment of three types of industrial wastewater (petrochemicals, foodstuffs, and sugar beet industries) and confirmed that the electro-Fenton was more efficient and cost-effective than the Fenton process.Wang et al.[21] used zero-valent iron as a catalyst for the compounding of peroxymonosulfate and electro-Fenton to form the ZVI-E-Fenton-PMS method for the treatment of wastewater and found that the methylene blue removal and the reaction rate constants of this process were much higher than those of other processes and that it also had a high removal rate of other difficult-to-degrade organic pollutants and that this process had a great potential for application. Zhang et al.[22] used graphene aerogel-loaded UiO-66-NH_2-(Zr) bound to atomic Fe(III) and found that when UiO-66-NH_2-(Zr/Fe) nanoparticles were confined by a graphene aerogel substrate, the resulting composite showed a great improvement in phenol removal and a significant reduction in carbon emissions.

2.3 Biological treatments

Biological treatment is a wastewater treatment method that utilizes microorganisms in the natural environment to oxidize and decompose organic pollutants and certain inorganic toxic pollutants in wastewater and convert them into stable and harmless inorganic substances. Aerobic biological treatment technology utilizes the biochemical action of aerobic organisms and parthenogenetic anaerobic organisms to degrade organic matter, while anaerobic biological treatment technology utilizes the action of anaerobic organisms to degrade pollutants. The anaerobic-aerobic process is to connect the anaerobic section and aerobic section in series, and its superiority lies in the fact that in addition to the degradation of organic pollutants, it also has a certain function of denitrogenation and phosphorus removal, and the anaerobic-aerobic process well combines the treatment characteristics of each of the anaerobic and aerobic processes[23]. Kong et al.[24] used an anaerobic membrane bioreactor to treat the high concentration of N,N-dimethylformamide (DMF)-containing industrial wastewater with N,N-dimethylformamide (DMF). The bioenergy recovered from the wastewater was able to completely cover the energy consumed for operation, and the process reduced CO_2 emissions by 57.8%. Rong et al.[25] studied the effect of temperature drop on membrane contamination using a 5000L anaerobic membrane bioreactor. The results showed that inorganic pollutants played a major role in residual contamination of membranes, and a staged control method was proposed to mitigate the membrane contamination on the basis of the experiments. A staged control method was proposed to mitigate the fouling.Thongsaia et al.[26] operated four hollow fiber membrane AnMBR systems with different levels of intermittent liquid recirculation, combined with biogas recirculation and activated carbon fluidization, and the results showed that all the reactors de-emphasized COD removal by more than 84%, and energy consumption was reduced by 23%.

2.4 Combined processes

Industrial wastewater usually has a complex composition and contains a variety of difficult-to-biodegrade organics, and it is difficult for a single process to meet the discharge standards, so a combination of physical, chemical and biological treatment processes is needed. Zhao Fan et al.[27] proposed a combined EGSB-SBR-ozone oxidation process to observe the treatment effect of SAR waste acid concentration condensate, RO concentrated water, maleic anhydride wastewater and PPG wastewater after mixing, and the results showed that the COD removal rate was higher and the treatment of the target mixed wastewater was better. For the characteristics of wastewater with complex composition, high concentration of pollutants and poor biochemistry, Guan Yongnian designed and developed a combined treatment process of hydrolysis acidification + two-stage AO/MBR + ozone catalytic oxidation + BAF (DN type) + air flotation + sodium hypochlorite disinfection, and the analysis during the trial operation found that the pollutant removal rate was higher and the operation was more stable, in which hydrolysis acidification tank can convert part of the organic nitrogen into NH_3 -N, and at the same time, it can improve the biochemistry of wastewater. Zhu et al. used an electrodeposition-chemical precipitation-electrooxidation process to recover copper and silicate, and $CaCl_2$ was selected as the precipitant in the chemical precipitation process, and through the electrodeposition and precipitation process, the recovery rate of copper could reach more than 99.8%, and the recovery rate of silicate had 89.7%, and the electrooxidation process could remove 96.4% of the COD, showing good results in wastewater treatment.

3. Discussion and conclusion

In the field of industrial water treatment, various methods have their unique advantages. Ceramic membrane filtration technology utilizes the high strength and chemical resistance of ceramic materials to treat industrial wastewater with high concentration and high solids content, and the stability of ceramic membranes allows them to operate efficiently at high temperatures and pressures. Advanced oxidation method with strong oxidizing ability to quickly degrade the water difficult to remove organic pollutants, in the treatment of high concentration of organic wastewater shows excellent results. In the combination of aerobic and anaerobic methods, the anaerobic stage can effectively degrade the high concentration of organic matter under anaerobic conditions and produce biogas for energy recovery; the aerobic stage can further remove residual organic matter and nutrient salts to ensure that the effluent water quality meets the emission standards.

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