REVIEW ARTICLE

Emerging trends in process optimization and technological innovation for modern wastewater treatment

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The wastewater treatment field currently faces pressures from the increasing complexity of pollutant types, continuously tightening treatment standards, and growing energy consumption and carbon emission constraints. Modern wastewater treatment processes are undergoing continuous optimization and innovation aimed at enhancing treatment efficiency, reducing energy consumption, and achieving resource recovery, ultimately establishing a more sustainable water cycle system. This review examined technological advancements and process optimization in modern wastewater treatment systems in terms of novel biological treatment technologies, novel physicochemical treatment methods, energy and resource recovery, and intelligent control and digital management. The analysis indicated that the ongoing development of these processes was characterized by multi-technology integration, synergistic utilization of energy and resources, and intelligent regulation.

Keywords: wastewater treatment; biological treatment; physicochemical treatment; energy and resource recovery; intelligent control; digital management.

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Introduction

Wastewater treatment has developed over thousands of years. Around 3000 BCE, ancient India and China were already applying clarification using plant materials and sedimentation for primary wastewater treatment, while ancient Greece and Rome built drainage systems and underground sedimentation tanks, reusing wastewater for irrigation or discharging it into natural water bodies. From the Middle Ages to the beginning of the Industrial Revolution, wastewater treatment methods remained largely limited to physical separation and land irrigation. In the mid-19th century, Britain promoted the widespread adoption of sewage collection systems through the Public Health Act, and chemical coagulation and biological filtration began to be applied. By the beginning of the 20th century, the development of the activated sludge process marked the birth of modern biological treatment technology, after which processes such as nitrification–denitrification and anaerobic digestion were gradually refined. Today, wastewater treatment mainly faces the following pressures and challenges.

1. Growing complexity of pollutant types

The primary challenge currently facing wastewater treatment lies in the growing complexity of pollutant types. Its drivers include the diversification of industrial production, changing lifestyles, the intensification of agricultural production [1], and the widespread use of emerging chemical substances. As a result, pollutants in wastewater have expanded beyond conventional organic matter, suspended solids, and nutrients to include persistent organic pollutants, trace toxic substances, emerging environmental endocrine disruptors, antibiotics, and antibiotic resistance genes. They are not only complex in composition and diverse in origin, but also characterized by low concentrations, high toxicity, strong bioaccumulation, and environmental persistence, posing substantial pressure on existing wastewater treatment technologies and threatening the safety of aquatic ecosystems and human health. Across industrial wastewater, domestic sewage, agricultural wastewater, and cross-media migration and transformation, pollutant characteristics and treatment difficulties are intertwined, together shaping the complex landscape currently confronting wastewater treatment [2].

2. Pressure from improving wastewater treatment standards

Another major challenge currently facing the wastewater treatment sector is the wide-ranging pressure created by continuously tightening wastewater treatment standards, which roots from increasing global attention to the protection of aquatic ecosystems, growing public expectations for water quality, and the introduction of stricter policies and regulations across countries and regions. In response, monitoring indicators have gradually expanded from conventional organic matter indicators such as Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) to encompass total nitrogen, total phosphorus, heavy metals, persistent organic pollutants, and microbial indicators [3]. The tightening of these standard requirements and the expansion of regulatory scope not only raise the performance demands placed on wastewater treatment technologies, but also increase operating costs, monitoring difficulties, and management complexity. The ripple effects extend across all stages of wastewater treatment, from process selection and facility renovation to operation and maintenance, monitoring and supervision, and are particularly evident in industrial, urban, and agricultural settings. As standards become more refined and stringent, these pressures continue to propagate and intensify [4].

3. Pressure form energy consumption and carbon emissions

The wastewater treatment process spans wastewater collection, treatment, sludge disposal, and the associated energy supply. Throughout this chain, energy consumption and carbon emissions are influenced by treatment technology, equipment operation modes, energy structure, and chemical dosing. High energy use and carbon emissions not only raise treatment costs but also exacerbate climate change, so cutting both is central to sustainable wastewater treatment. Overcoming this challenge requires measures on multiple fronts including technological innovation, process optimization, and adjustments to the energy mix [5]. To meet these challenges, coordinated action is required across pollutant source control, treatment technology innovation, monitoring system improvement, and policy and legal strengthening, from the development of efficient, low-cost, and multifunctional wastewater treatment technologies to the establishment of a comprehensive pollutant monitoring network and the promotion of stronger cross-domain and interdisciplinary collaboration. Only through such integrated efforts, the problems created by these pressures and challenges can be effectively addressed, which will steer the wastewater treatment sector toward higher quality and more sustainable development [6].

Wastewater treatment process optimization strategies

1. Novel biological treatment technologies

Within wastewater treatment process optimization, bioaugmentation relies on the screening and cultivation of high-efficiency bacterial strains to overcome the limitations of conventional biological treatment [7], while the hybrid biofilm–activated sludge process integrates the respective advantages of two established biological treatment paradigms [8].

(1) Screening and cultivation of high-efficiency bacterial strains

Conventional biological treatment processes such as activated sludge and anaerobic digestion suffer from several well-documented limitations including low microbial community activity exemplified by slow nitrifier proliferation and ammonia nitrogen removal of only 60 - 70%, poor adaptability with efficiency drops of more than 30% under low-temperature or high-salinity conditions, and narrow functional coverage notably the difficulty in degrading complex industrial organic matter. To circumvent these bottlenecks, high-efficiency bacterial strains with specific metabolic functions such as *Pseudomonas* for degrading phenols, *Nitrospira* for nitrification, and *Methanosarcina* for methane production are selectively enriched and their culture conditions optimized for large-scale proliferation. When applied to industrial organic wastewater, high-salinity wastewater [9], or low-temperature wastewater, the introduced strains improve pollutant degradation efficiency and strengthen process resistance to shock loads, thereby providing key technical support for upgrading conventional biological treatment processes [10].

(2) Hybrid biofilm and activated sludge process

The hybrid biofilm–activated sludge process was developed to address the limitations of the traditional activated sludge method such as poor sludge settling performance that SVI often exceeding 150 mL/g, leading to sludge leakage in the secondary sedimentation tank, weak shock load resistance that a 20% fluctuation in influent COD causing a 15% decrease in treatment efficiency, and a large footprint owing to the separate installation of sedimentation tanks and aeration tanks. Meanwhile, the traditional biofilm method like biofilter and biorotor has limitations such as low mass transfer efficiency due to high resistance to pollutant diffusion into the biofilm, difficulty in biomass control as excessively thick biofilms readily slough off and increase effluent SS, and limited removal capacity for low-concentration pollutants with removal rates < 60% when COD < 100 mg/L. By introducing biofilm carriers such as suspended fillers and fixed fillers into the activated sludge reaction system [11], a combined "suspended activated sludge + attached biofilm" configuration is constructed. This dual-microorganism system achieves efficient pollutant degradation, improved process stability, and reduced land occupation in municipal wastewater, industrial organic wastewater [12], and low-concentration wastewater containing refractory organics, making it an important direction for upgrading traditional biological treatment processes [13]. In a previous report of one municipal wastewater treatment plant, suspended carriers were added to the original aeration tank without constructing new structures, and the COD removal rate increased from 80% to 88%. In a split configuration, a biofilm tank provides pretreatment, for example the removal of refractory organic matter, while an activated sludge tank provides advanced treatment including denitrification and phosphorus removal for high-concentration industrial wastewater. A representative case was reported that a coking plant that employed a series configuration combining "biofilm tank for phenol removal + activated sludge tank for COD and nitrogen removal" arrangement, achieving a phenol removal rate of 95% and a total nitrogen removal rate of 80%, effectively resolving the difficulty that traditional single processes face in balancing the removal of multiple pollutants. However, the hybrid process still faces several challenges including the wear of suspended carriers during long-term operation with an annual loss rate of 5 - 10%, the fluctuation of denitrification efficiency caused by oxygen limitation in the inner biofilm

layer, and the inhibitory effect of high-concentration industrial wastewater containing heavy metals and highly toxic substances on the biofilm. Future breakthroughs will depend on carrier material innovation such as the development of wear-resistant ceramic carriers, process structure optimization such as adding internal circulation to improve mass transfer, and pretreatment enhancement such as chemical precipitation to remove heavy metals. Collectively, these advances promote wider application of the hybrid biofilm–activated sludge process in conventional wastewater treatment and support the upgrading of biological treatment toward "high efficiency, stability, and compactness" [14].

2. Novel physicochemical treatment technologies

Novel physicochemical treatment technologies mainly include breakthroughs in membrane separation technology and new advanced oxidation processes [15, 16].

(1) Breakthroughs in membrane separation technology

Among innovative wastewater treatment technologies, the combined application of ultrafiltration and reverse osmosis is a core solution to the limitations of traditional wastewater treatment processes such as activated sludge and coagulation sedimentation, which are characterized by incomplete removal of small-molecule pollutants like salts and trace organic residues, low effluent reuse rates often below 50%, and high risks of secondary pollution arising from chemical residues and sludge disposal issues [17]. In the dual-membrane configuration, the "pretreatment + fine filtration" function of ultrafiltration is paired with the "desalination + purification" function of reverse osmosis to form an integrated treatment system. Applied in municipal wastewater reuse, high-salinity industrial wastewater treatment, seawater desalination, and special wastewater purification, the system significantly improves effluent quality, achieving COD in reclaimed water below 10 mg/L and total salt content below 500 mg/L, while also raising the water resource recovery rate to a reuse rate exceeding 80%. These performance gains have positioned the dual-membrane process as a key innovative technology for "near-zero discharge" and "resource recovery" in the current wastewater treatment field. Forward Osmosis (FO) as a new membrane separation technology distinct from traditional pressure-driven membrane technologies such as ultrafiltration and reverse osmosis, exploits the osmotic pressure gradient across a semipermeable membrane to drive the natural migration of water molecules without external pressure [18]. This operating principle endows FO with low energy consumption typically 1.0 – 4.0 kW·h per m^3 of wastewater treated, strong fouling resistance, and high compatibility. In practice, FO achieves salt removal rates of 80 - 95% and organic matter removal rates of up to 90% in scenarios ranging from municipal wastewater reuse and volume reduction of high-salinity industrial wastewater to seawater desalination and landfill leachate treatment [19]. Compared with traditional reverse osmosis, FO saves 30 – 60% in energy consumption and reduces the use of chemical agents, as only a small amount of draw solution is needed for regeneration. Taken together, these attributes make FO an important innovation direction for advancing wastewater treatment toward "low carbon, resource recovery, and near-zero discharge"

(2) Advanced oxidation processes

Among emerging advanced oxidation technologies, the design of photocatalytic oxidation reactors is the core strategy for overcoming the limitations of traditional advanced oxidation processes [20], namely Fenton oxidation and ozone oxidation [21], which are plagued by high energy consumption typically 5 - 10 kW·h per m^3 of refractory wastewater, large reagent dosage, for example, H_2O_2 dosage of 500 – 1,000 mg/L in the Fenton process, and poor selectivity manifested as low degradation efficiency for specific pollutants. By optimizing light source configuration, catalyst carrier structure, reaction flow field distribution, and

mass transfer efficiency, researchers have constructed a high-efficiency "light-catalyst-pollutant" interaction system [22]. When applied to refractory industrial wastewater such as pharmaceutical, printing and dyeing, and coal chemical wastewater, deep treatment of municipal wastewater, or removal of micropollutants such as antibiotics and endocrine disruptors, the optimized system achieves deep mineralization of organic pollutants with COD removal of 80 - 95% and TOC removal of 60 - 85%, while cutting energy consumption by 40 - 60% compared to traditional ozone oxidation and minimizing reagent consumption, since only a small amount of catalyst regeneration reagent is needed. Photocatalytic oxidation thus stands as an important innovation direction for driving advanced oxidation technology toward "high efficiency, low carbon, and precision" [23]. A parallel line of innovation targets electrochemical oxidation [24, 25], where improving efficiency is a core challenge giving the shortcomings of traditional configurations such as two-dimensional plate electrode electrolysis and conventional dimensionally stable anode (DSA) electrode treatment including high energy consumption of 15 - 30 kW·h per m^3 of refractory wastewater, low current efficiency usually below 30%, short electrode life with DSA electrodes lasting only 3,000 – 5,000 h, and limited treatment effect on high-concentration complex wastewater with COD removal below 60%. Recent progress has been made through electrode material innovation like the development of new electrodes with high catalytic activity and extended stability [26], reactor structure optimization like three-dimensional electrode reactors and flow electrolysis reactors, precise control of process parameters such as current density, pH value, and electrolyte concentration, and coordinated integration with other processes like electrochemical oxidation coupled with biological treatment or membrane separation. These advances have enabled efficient degradation of organic pollutants and can be achieved in scenarios such as refractory industrial wastewater like pharmaceutical, coking, and printing and dyeing wastewater, high-salinity organic wastewater, and deep treatment of landfill leachate, achieving COD removal of 80 - 95% and current efficiency of 50 - 80%, while reducing energy consumption by 30 - 60% compared with traditional processes and extending electrode life to 8,000 – 15,000 h. Altogether, these developments provide an important innovative path for transforming electrochemical oxidation toward "high efficiency, low energy consumption, and long service life" [27, 28].

3. New Materials and New Chemicals

Within process optimization for wastewater treatment, the development of high-efficiency adsorption materials and environmentally friendly flocculants is a key direction for overcoming the limitations of traditional wastewater treatment approaches [29, 30].

(1) High-efficiency adsorption materials

Traditional processes such as activated sludge and coagulation–flocculation exhibit notable shortcomings when dealing with low-concentration pollutants such as heavy metal ions, trace organic matter, phosphorus, and nitrogen, specified as removal efficiency often falls below 60%, chemical dosages are large with coagulant dosage exceeding 50 mg/L, and secondary pollution risks are high owing to the generation of large amounts of chemical sludge. Improving conventional adsorption materials and developing new ones can overcome these bottlenecks by achieving precise adsorption and high-efficiency separation in treatment scenarios spanning heavy metal wastewater, refractory organic wastewater, and eutrophic wastewater, all while reducing treatment costs and environmental risks. Such advances provide important technical support for upgrading traditional wastewater treatment processes [31]. For example, modified activated carbon targets the low adsorption capacity and poor selectivity inherent in traditional activated carbon [32]. Biochar, derived from agricultural waste of straw, rice husks, and peanut shells, offers a cost-

effective and renewable alternative to conventional granular activated carbon (GAC), whose feedstocks are non-renewable. The development of nanocomposite adsorbent materials addresses the insufficient adsorption capacity of traditional materials for trace pollutants such as antibiotics and endocrine disruptors at the ng/L level [33]. Metal-organic frameworks (MOFs), a class of porous crystalline materials with tunable pore architecture, overcome the limited pore size control and single functionality that constrain conventional adsorbents [34].

(2) Environmentally friendly flocculants

Traditional flocculants encompassing inorganic polymer flocculants such as polyaluminum chloride (PAC) and polyferric sulfate (PFS), as well as organic synthetic flocculants such as polyacrylamide (PAM) carry significant secondary pollution risks including ecotoxicity concerns from residual aluminium ions in PAC, neurotoxicity hazards from residual monomers in PAM, the narrow applicable pH range, for example, PFS being only effective at pH 5 - 9, and high sludge production with moisture content exceeding 98% after chemical addition [35]. Developing natural polymer modified flocculants, microbial flocculants, and composite environmentally friendly flocculants can reconcile efficient flocculation with environmental friendliness in treatment scenarios ranging from municipal wastewater and industrial wastewater to rural decentralized wastewater, thereby reducing chemical consumption and sludge disposal costs and providing key technical support for upgrading traditional coagulation–flocculation processes [36]. For example, natural polymer modified flocculants are designed to eliminate toxic residues and poor biodegradability associated with traditional synthetic flocculants [37]. Microbial flocculants, produced from microbial metabolites such as polysaccharides, proteins, and nucleic acids or microbial cells, break the dependence on fossil resources as PAM raw materials are derived from petroleum and offer inherent biodegradability [38]. Composite environmentally friendly flocculants leverage the synergistic effect of different green components to compensate for the performance shortcomings of single agents, for instance, the slow flocculation rate of natural polymer flocculants and the poor stability of microbial flocculants.

4. Intelligent control and digital management

Within process control optimization for wastewater treatment, the real-time monitoring and feedback system and process adjustment strategies for energy saving and consumption reduction are the core technical means.

(1) Real-time monitoring and feedback system

A real-time monitoring and feedback system integrates sensor networks, data transmission, data analysis, and control execution modules into a unified closed-loop architecture. During operation, the system collects key parameters from each stage of wastewater treatment in real time including water quality indicators, equipment operating status, and environmental conditions, generates control instructions based on preset thresholds or algorithm models, and in turn adjusts process operating parameters such as aeration intensity, chemical dosage, and influent flow. The resulting closed-loop control directly overcomes the limitations of traditional wastewater treatment that relies on manual monitoring, namely delayed response, experience-based parameter adjustment, and large fluctuations in treatment performance. In practice, such systems have proven particularly valuable for optimizing traditional processes such as activated sludge, anaerobic treatment, and coagulation–flocculation, which improves treatment efficiency, reduces energy consumption costs, and stabilizes effluent water quality [39].

(2) Process adjustment for energy saving and consumption reduction

Traditional wastewater treatment processes are characterized by concentrated energy consumption and low energy utilization efficiency with aeration alone accounting for 50 -

70% of total energy use, sludge treatment for 20 - 30%, biogas recovery rate below 50%, and excessive hydraulic conveyance energy consumption. To break through this bottleneck, energy consumption is reduced in key stages such as activated sludge, anaerobic treatment, sludge disposal, and the hydraulic system by optimizing process parameters, improving equipment configuration, and reconstructing process structure. Crucially, the treatment performance is stabilized, providing an important pathway for traditional wastewater treatment processes to meet the growing demands of low-carbon development [40].

5. Energy and resource recovery

In the pursuit of resource recovery for innovative wastewater treatment technologies and application cases, phosphorus recovery and biogas power generation coupled with thermal energy utilization are two representative areas for overcoming the limitations of traditional wastewater treatment processes [41, 42].

(1) Phosphorus recovery technology and applications

Traditional wastewater treatment processes such as activated sludge and chemical coagulation exhibit several critical shortcomings with respect to phosphorus management including incomplete phosphorus removal with total phosphorus removal rates below 80% and effluent total phosphorus often exceeding 0.5 mg/L, phosphorus resource waste as phosphorus is typically converted into sludge for landfill and leaved unrecoverable, and high sludge disposal costs since phosphorus-containing sludge requires anti-seepage treatment that increases costs disposal by 30%. Phosphorus recovery technologies address these shortcomings through chemical precipitation, adsorption, biologically induced crystallization, and membrane separation, achieving efficient phosphorus separation with total phosphorus removal rates of 90 - 99% and resource recovery with recovered products mainly consisting of calcium phosphate and struvite at purities of 85 - 98% [43]. These technologies have been successfully applied in municipal wastewater, aquaculture wastewater, and industrial phosphorus-containing wastewater such as chemical and food processing wastewater. Beyond that, such approaches also reduce sludge production by 20 - 40% compared with traditional processes and increase wastewater reuse value with effluent total phosphorus below 0.1 mg/L and thus meeting stringent effluent phosphorus limits. Overall, phosphorus recovery has emerged as an important innovative path for driving the transformation of wastewater treatment from “pollutant removal” to “resource recovery” [44, 45].

(2) Biogas power generation and thermal energy utilization

Traditional wastewater treatment processes suffer from high energy consumption as 0.3 - 0.8 kW·h per m^3 of wastewater treated, low resource utilization rate of organic pollutants with only 30 - 50% being converted to methane, and severe heat loss where only 50 - 60% of the energy in biogas produced by anaerobic digestion is used for power generation and the remaining heat energy is directly discharged. To overcome these inefficiencies, recent efforts have focused on three complementary strategies including optimizing the anaerobic digestion process to increase biogas production and methane concentration, improving the biogas purification system to reduce impurity content and ensure power generation efficiency, and building a closed-loop strategy linking "power generation - heat recovery - process reuse" [46]. Under this configuration, waste heat from power generation is redirected to anaerobic digestion heating, heat preservation, sludge drying, and similar thermal demands. Applied in municipal wastewater, aquaculture wastewater, and industrial organic wastewater including food processing and brewing wastewater, the integrated system achieves efficient conversion of organic pollutants into clean energy with biogas yield increased to 0.4 - 0.6 m^3/kg COD and methane concentration reaching 60 - 75%. Meanwhile, energy consumption is reduced by 40 - 60% compared with traditional processes, and the

energy self-sufficiency rate exceeds 80% in some projects. These gains have positioned biogas-based energy recovery as an important innovative path for advancing wastewater treatment from "high energy consumption" to "energy self-sufficiency" [47].

Future development trends

1. Low-carbon development and resource recovery

Against the backdrop of global "dual carbon" goals and intensifying water scarcity, the future development of the wastewater treatment industry is converging on two core areas including decarbonization and resource recovery. Resource recovery achieves the value transformation of wastewater into resources by efficiently extracting and recycling water resources, energy like biogas, nutrients like nitrogen and phosphorus, and metal resources from wastewater. To achieve this goal, process optimization and energy structure adjustments are aimed at minimizing carbon emissions throughout the entire wastewater treatment lifecycle. The two directions reinforce each other, giving rise to a large number of technological innovations and practical cases worldwide across municipal wastewater, industrial wastewater, and agricultural wastewater [48, 49].

2. Intelligent and automated technologies

The deep integration of advanced technologies into the wastewater treatment process enables precise perception, intelligent decision-making, automatic control, and efficient operation and maintenance across the entire treatment chain [50]. Driven by this integration, the wastewater treatment industry is accelerating its transformation toward intelligence and automation. This shift not only improves the stability and efficiency of wastewater treatment but also reduces operating costs and labour dependence [51]. From real-time water quality monitoring to automatic control of process parameters, and from intelligent equipment operation and maintenance to plant-wide intelligent management, these technologies have permeated every aspect of wastewater treatment. Replicable and scalable practical cases have emerged in wastewater treatment facilities of different scales and types worldwide, charting a clear technical path for the transformation and upgrading of the industry [52, 53].

3. Interdisciplinary integration and innovation

As wastewater treatment technology advances toward higher efficiency, lower carbon emissions, and better resource utilization, knowledge from any single discipline alone is no longer sufficient to meet the complex needs of wastewater treatment. Therefore, the deep integration and collaborative innovation of interdisciplinary theories, methods, and technologies drawn from environmental science and engineering, materials science, microbiology, information technology, ecology, and chemical engineering have become the core driving force for industry development. By breaking down disciplinary barriers and restructuring the wastewater treatment technology system, interdisciplinary collaboration has effectively addressed challenges beyond the reach of traditional processes including the removal of recalcitrant pollutants, low-energy resource recovery, and the implementation of environmentally friendly treatment solutions. Globally, a growing number of case studies have demonstrated the transformative potential of this collaboration, paving a new path for the wastewater treatment industry.

Conclusion

The main pressures currently facing the field of wastewater treatment arise from the increasing complexity of pollutant types, the continuous tightening of discharge standards, and the growing constraints on energy consumption and carbon emissions. In response, advances in modern wastewater treatment processes are driving technological innovation in environmental engineering with the core goals of

improving treatment efficiency, reducing energy consumption, and achieving resource recovery, ultimately building a more sustainable water cycle. This study reviewed the technological advancements and optimization of modern wastewater treatment systems across novel biological treatment technologies, physicochemical treatment technologies, energy and resource recovery, and intelligent control and digital management. It revealed that the continuous development of modern wastewater treatment processes was characterized by the integration of multiple technologies, energy and resource synergy, and intelligent regulation. Crucially, these innovations extended beyond improving end-of-pipe treatment effectiveness but integrated the entire treatment process into a circular economy framework, thereby playing an increasingly critical role in aquatic environment governance and sustainable development.

References

1. Zhou NL. 2020. Treatment technology of chemical synthetic pharmaceutical wastewater. Chem Eng Design Commun. 46(8):50-51.
2. Fei YC. 2025. Technological innovation and energy saving and consumption reduction in sewage treatment. Cleaning World. 41(1):81-83.
3. Wang YX, Tie JX, Li RH. 2026. Research progress on coagulation for removing micro-nano plastics and their composite pollutants. Chem Ind Eng Prog. 2026:1-15.
4. Tao RF. 2024. Numerical simulation of urban drainage networks and efficiency improvement of wastewater treatment plants under the background of "Double Carbon". Chongqing Jiaotong University.
5. Zhang YJ. 2025. Optimization of energy-saving processes in the reuse and treatment of petrochemical wastewater. Shanxi Chemical Industry. 45(8):209-211.
6. Jia L. 2025. Innovative methods and energy-saving practices for urban domestic sewage treatment technology. Heilongjiang Environmental Journal. 38(6):114-116.
7. Feng HM. 2025. Analysis of the application of biological enhancement technology in water pollution control. Leather Manufacturing and Environmental Technology. 6(11):5-7.
8. Feng QR. 2023. Deep nitrogen removal performance of activated sludge suspended biofilm system for treating low C/N ratio wastewater. Environ Chem. 42(5):1697-1707.
9. Liu ZY, Zhang B, Yang J. 2025. A review of research progress on biological treatment technology for high-salt organic wastewater. J Green Sci Technol. 27(16):101-107, 132.
10. Wang L, Zhang W. 2026. Research on bioaugmentation process in high ammonia nitrogen wastewater treatment. Leather Manufacturing and Environmental Technology, 7(7):25-27.
11. Huang L, Zhong CM, Ye JM, Zhang Y, Huang DL, Yang QQ. 2025. Influence of suspension carriers on the efficacy of MBR process in treating ammonia-nitrogen wastewater, sludge properties and microbial community changes. Technol Water Treat. 51(11):97-103.
12. Chen HL, Gao H, Chen JB, Wang HC, Qi L, Liu GH, *et al*. 2023. The emission reduction effect of biological carriers in the IFAS process for wastewater treatment on N_2O. Petroleum Processing and Petrochemicals. 54(7): 113-122.
13. Ding S, He J, Luo X, Zheng Z. 2020. Simultaneous nitrogen and carbon removal in a packed A/O reactor: Effect of C/N ratio on microbial community structure. Bioprocess Biosyst Eng. 43(7):1241-1252.
14. Gu JY, He GF, Lin N. 2016. Study on bacterial diversity and key denitrification bacteria in integrated fixed-film activated sludge system. Env Eng. 34(8):36-39, 49.
15. Cai YY, Bao BY. 2025. Research progress on the application of membrane separation technology in the biopesticide industry. Modern Industry. 45(12):41-45, 53.
16. Li MX. 2023. Theoretical research on the degradation mechanism of nitrogen-containing organic micropollutants in the new advanced oxidation process. Shandong University.
17. Li XF. 2025. Application of the combined process of physicochemical treatment-AO-MBR-ultrafiltration-reverse osmosis in the wastewater treatment of domestic waste transfer station. Guangdong Chemical Industry. 52(17):74-76.
18. Xu M, Zhao PY, Tang C, Yi X, Wang X. 2022. Preparation of electrically enhanced Forward Osmosis (FO) membrane by two-dimensional MXenes for organic fouling mitigation. Chin Chem Lett. 33(8):3818-3822.
19. He MD. 2025. Study on the performance and membrane fouling of forward osmosis–membrane distillation (FO-MD) system for transfer stations leachate concentration. University of The South.
20. Liu LG. 2023. Study on photocatalytic oxidation technology for in-situ treatment of phosphorus pollution in river channels. Shanxi Chemical Industry. 43(9):191-194.
21. Song LJ. 2020. Contrast of aniline-contaminated groundwater treatment by Fenton and ozone oxidation. Water Purification Technology. 39(8):102-108.
22. Bao Z, Wu Y, Lin T, Zhan L, Xia Z, Fu H. 2025. Z-Scheme BiOCl-Bi2WO6 photocatalyst: Carrier separation mechanism and enhanced antibiotic degradation. J Environ Eng. 19(12):3209-3221.
23. Arulsamy JJ, Prunier JPH, Arockiasamy FF, Irudhayaraj J, Thaninayagam E, Ravi GR, *et al*. 2025. An investigation of silver-nanoparticle-modified TiO_2 substrates for photocatalytic oxidation in wastewater treatment. Nanotechnol Precis Eng. 8(3):22-32.

24. Nie HF, Li SS. 2025. Study on the removal of difficult to degrade pollutants by electrochemical catalytic oxidation method. Chemical Industry Management. 2025(36):50-54.
25. Chen L, Wei L, Ru Y, Weng M, Wang L, Dai Q. 2023. A mini-review of the electro-peroxone technology for wastewater: Characteristics, mechanism and prospect. Chinese Chemical Letters. 34(9):25-32.
26. Zhou YH, Cai XR, Wang YH, Sun JF. 2025. Research progress on the preparation of TiO_2 by micro-arc oxidation in the fields of photocatalysis and electrochemical energy storage. Material Protection. 58(11):79-87.
27. Han Y, Hu XL. 2025. Research progress on the electrochemical treatment of refractory organic compounds in wastewater by electrode BDD. Chem Eng. 39(10):80-84, 73.
28. Wang XX, Zhu FJ, Wang YY, Wu JJ, Liu PB, Xue YZ. 2025. Research progress on mechanism of electrocatalytic oxidation of ammonia nitrogen and treatment of practical wastewater. Chem Eng Commun. 51(10):119-124, 132.
29. Huang YY, Li R, Chen JX, Deng JM, Zhu BH, Lu FL, *et al*. 2026. Preparation of magnetic chitosan-based adsorbent and progress of water treatment applications. Chem Ind Eng Prog. 45(2):923-935.
30. Niu ZR, Ji PX, Feng SJ, Wu XY, Zeng DF. 2025. Research on the development and application of a new type of environmentally friendly water filtration agent for tap water. Yunnan Chemical Industry. 52(12):47-49.
31. Shi XZ. 2025. Preparation of composite porous materials from coal gasification fine slag and study on the adsorption mechanism of heavy metals and organic dyes. Southwest University of Science and Technology.
32. Li XY. 2025. Adsorption of methyl orange by activated carbon from rice husk modified by sodium hydroxide. Guangzhou Chemical Industry. 53(20):127-130.
33. Gong L. 2024. Preparation and adsorption performance characterization of adsorbent bentonite nanocomposite materials. Chemistry and Adhesion. 46(4):363-367.
34. Wu H. 2025. Synthesis of metal-organic framework materials containing pyridine ligands and adsorption of Pb^{2+} in water and gaseous iodine. University Of Yantai.
35. Liu W, Ma JJ, Yao XD, Wang ZW, Fang RN, Cheng L. 2018. Research progresses on starch flocculants for water treatment. Environmental Protection of Chemical Industry. 38(2):141-147.
36. Zheng J. 2021. Synthesis mechanisms of natural organic polymer flocculants and its application in removal of refractory organic pollutants. Industrial and Commercial University of Chongqing.
37. Luo YL, Wang XT, Gao M, Li XY, Yeerken, Lin JL. 2022. Research progress in preparation of modified natural polymer flocculants. Polymer Bulletin. 35(8):1-11.
38. Zhao C, Huang BJ, Zhang X, Huang J, Chen YL, Man ZZ, *et al*. 2025. Preparation of microbial flocculant by *Paenibacillus polymyxa* GA1 using *Camellia oleifera* cake as an alternative medium and prediction of biosynthetic pathway genes. Acta Scientiae Circumstantiae. 45(07):215-230.
39. Guo CL, Han RB. 2025. Development of PLC-based online monitoring and control system in sewage treatment. Automation Application. 66(15):9-11.
40. Chen P, Ding LT, Guo SL. 2024. Discussion on energy-saving technologies in the upgrading of wastewater treatment plants. China Resources Comprehensive Utilization. 42(9):236-238.
41. Cai L, Tang YC, Wu CN, Huang XH, Li WH. 2025. Research progress on phosphorus recovery theory and technology in wastewater treatment. Applied Chemistry. 54(07):1841-1846.
42. Luo B, Liu LP, Wang W, Fei WW. 2024. Electrical design for the biogas power generation project of the new sewage treatment plant of a brewery. Mechanical and Electrical Engineering Technology. 53(6):277-281.
43. Chen SQ. 2025. Research on efficient treatment of sewage sludge and synchronous phosphorus recovery based on biological predation. Harbin Institute of Technology.
44. Liu XR. 2024. Research progress of phosphorus recovery technology in wastewater. Liaoning Chemical Industry. 53(12):1933-1936.
45. Li Z. 2024. Investigation on the formation of persistent free radicals in Fenton-conditioned sludge-based biochar and its mechanism for promoting phosphorus recovery. Huazhong University of Science and Technology.
46. Ni WZ, Zhang XD, Yang QP, Zheng KY, Yuan CJ, Zhou Z, *et al*. 2026. Carbon reduction benefit of photovoltaic power generation and alternative carbon source in wastewater treatment plant. Environmental Pollution and its Prevention and Control, 48(2):16-20.
47. Yao KW, Zhang X, Wang G. 2023. Application and case analysis of photovoltaic power generation in energy saving and emission reduction of sewage plant. Energy Efficiency and Environmental Protection, 2023(11):75-80.
48. Zhao C. 2025. Research on typical treatment models of rural domestic sewage in Shandong province guided by resource utilization. China Resources Comprehensive Utilization, 43(12):273-277.
49. Han TH. 2025. Research on waste heat recovery and application of sewage treatment system. China Resources Comprehensive Utilization. 43(9):80-83.
50. Zhou FM. 2024. Application research of artificial intelligence technology in wastewater treatment. China High-Tech Industry. 2024(16):19-21.
51. Zhao Y. 2022. Research on intelligent optimization and control methods for wastewater treatment processes. University of the South.
52. Hou YT, Guo N. 2025. Application and effect evaluation of intelligent technology in sewage treatment system. Henan Sci Technol. 52(11):4-7.
53. Ru XY. 2025. Research on the application of automated control technology in the wastewater treatment process. Instrument and Meter User. 32(4):24-26.