Industrial Park Wastewater Treatment Project Design and Effluent Discharge Optimization

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Keywords: Industrial Park; Wastewater Treatment; Effluent Discharge; Resource Utilization; Smart Management

Abstract: This paper systematically analyzes the necessity of wastewater treatment project construction across three dimensions: policy compliance, resource recycling, and cost optimization. It elaborates on key engineering design points, including quality-based separate collection and source reduction, precise configuration of pretreatment units, biochemical system shock resistance design, and modular reservation in advanced treatment. Furthermore, optimization strategies for effluent discharge are proposed focusing on four aspects: compliance monitoring with dynamic adjustments, ecological buffering and risk prevention/control, reclaimed water recycling and resource utilization, and smart management for operational assurance. The aim is to provide technical references for industrial parks to build efficient wastewater treatment systems and maximize water resource recycling.

1. Introduction

With the in-depth implementation of environmental policies like the Water Pollution Prevention and Control Action Plan, wastewater treatment in industrial parks is shifting from end-of-pipe treatment towards whole-process control, and upgrading from compliant discharge to resource utilization. Industrial wastewater today is characterized by increasingly complex compositions, higher concentrations, and greater treatment difficulty, making traditional single-treatment modes inadequate for meeting stringent discharge standards and reuse requirements. Against the backdrop of the "Dual Carbon" goals and tightening water resource constraints, achieving efficient wastewater treatment through scientific design and promoting effluent resource utilization through optimized management have become critical pathways for the green transformation of industrial parks.

2. Necessity of Wastewater Treatment Project Construction in Industrial Parks

Constructing wastewater treatment projects within industrial parks is an essential choice to address both environmental constraints and developmental needs. As the Water Pollution Prevention and Control Action Plan advances, industrial wastewater discharge standards are continuously raised. Parks, as concentrated pollution sources, face tremendous environmental pressure; lacking adequate treatment facilities could directly impact normal enterprise operations and park investment attraction. Water scarcity has become a bottleneck restricting industrial development. Deep treatment and resource utilization of wastewater can establish a "water intake - water use - wastewater discharge - reclaimed water" cycle, reducing dependence on freshwater resources [1]. Building centralized treatment facilities enables concentrated control and large-scale management of pollutants, avoiding redundant investments and management chaos caused by fragmented enterprise efforts. Furthermore, professional operation and management ensure stable and reliable treatment performance, laying a solid foundation for industrial upgrading and green development within the park.

3. Key Points of Industrial Park Wastewater Treatment Project Design

The core of industrial park wastewater treatment engineering lies in systematic design and refined management, requiring holistic consideration of the entire chain from wastewater generation, collection, treatment, to discharge, ensuring coordination across all stages.

  DOI: 10.25236/icacel.2025.112

3.1 Quality-Based Separate Collection and Source Reduction

Quality-based separate collection of industrial park wastewater requires systematic planning starting from pipeline network design. During the park's initial construction phase, dedicated collection pipelines should be pre-designed based on resident enterprise types, with heavy metal wastewater, high-salinity wastewater, and high-organic wastewater transported via different lines to their respective pretreatment units. For instance, chromium- and nickel-containing wastewater from electroplating workshops is collected through dedicated pipelines and fed into chemical precipitation tanks. Sodium sulfide or sodium hydroxide is added to convert heavy metals into precipitates for removal. The treated supernatant is then mixed with other production wastewater in a comprehensive equalization basin [2]. The equalization basin's design volume should consider the production shifts and discharge patterns of park enterprises, typically sized for 8-12 hours of average flow. Submersible mixers are installed to prevent solids deposition, and an automatic pH adjustment system maintains influent pH between 6.5 and 8.5. By installing electromagnetic flow meters and online water quality monitoring instruments, discharge ledgers for each enterprise are established. Automatic valve closure is implemented for enterprises exceeding discharge limits to control total pollutant load at the source.

3.2 Precise Configuration of Pretreatment Units

The selection of pretreatment processes must be based on detailed water quality analysis data. Variation patterns of indicators like COD, BOD, ammonia nitrogen, and total phosphorus are obtained through continuous monitoring over one month to determine the optimal treatment train. Fenton oxidation reactor design requires precise control of reaction conditions: pH adjusted to 3-4, ferrous sulfate and hydrogen peroxide dosed based on COD removal requirements (molar ratio controlled between 1:5-10), with a reaction time of 60-90 minutes. An aeration system enhances mass transfer, ensuring sufficient hydroxyl radical generation and reaction with organics. Dissolved Air Flotation (DAF) is selected, with a recirculation ratio set at 30-40% and saturation pressure maintained at 0.3-0.4 MPa. Polyaluminum chloride (PAC) and polyacrylamide (PAM) are used as coagulant and flocculant, respectively, with dosages determined by jar tests (typically PAC: 50-100 mg/L, PAM: 1-3 mg/L). A mechanically mixed clarifier is used for coagulation-flocculation-sedimentation, divided into mixing, reaction, and settling zones. Mixing time is 1-2 minutes, reaction time 15-20 minutes, and surface loading rate controlled at 1.5-2.5 $m^3/(m^2 \cdot h)$ to ensure effluent turbidity below 20 NTU.

3.3 Shock Resistance Design of Biochemical System

The shock resistance of the biochemical system depends on microbial community diversity and system buffering capacity. Anaerobic reactors use internal circulation or upflow designs, with volumetric loading rates controlled at 5-8 kg $COD/(m^3 \cdot d)$. Internal three-phase separators achieve gas-liquid-solid separation, maintaining sludge concentration at 20-30 g/L. The aerobic tank employs step-feed aeration, distributing influent to multiple points along the tank's front and middle sections to avoid localized organic overloading. Fine bubble diffusers are chosen, achieving oxygen transfer efficiency above 25%. Variable-frequency blowers automatically adjust aeration based on dissolved oxygen concentration. The sludge recirculation ratio (SRR) is set at 50-100%, and mixed liquor recirculation ratio (MLR) at 200-400%, ensuring sufficient microbial concentration within the system. An emergency dosing system is installed beside the biochemical tanks, stocked with carbon sources (e.g., glucose, methanol) and phosphate nutrients. These are supplemented promptly when the influent C/N ratio is imbalanced to maintain the nutritional balance (COD:N:P) of 100:5:1.

3.4 Advanced Treatment and Reuse Reservation

The advanced treatment system adopts a multi-barrier design concept. Suspended solids are first removed via multi-media filters, followed by activated carbon adsorption to remove soluble organics and color. Membrane separation systems provide final deep purification. Ultrafiltration

(UF) uses PVDF hollow fiber membranes with pore sizes of 0.01-0.1 μm. Operating pressure is 0.1-0.3 MPa, flux controlled at 60-80 L/(m^2·h), and backwashing (using 5-8% of the permeate volume) is performed every 30-40 minutes of operation. The reverse osmosis (RO) system uses a two-stage/two-pass configuration. The first stage achieves salt rejection above 97%, with a system recovery rate of 75%. The brine is pressurized by a high-pressure pump for further treatment in the second-stage RO [3]. Membrane units are designed modularly, with each module having a capacity of 500 m^3/d. Initially, 60% capacity is installed, with pipeline and electrical interfaces reserved for rapid expansion when flow increases. Permeate is collected based on conductivity grades: <100 μS/cm for boiler feed water makeup, 100-500 μS/cm for recirculating cooling water makeup, and 500-1000 μS/cm for landscaping and road cleaning, delivered via a dedicated reclaimed water distribution network to respective usage points.

4. Optimization Strategies for Industrial Park Wastewater Effluent Discharge

Effluent discharge optimization is critical for ensuring the long-term stable operation of the wastewater treatment system, requiring the establishment of a comprehensive monitoring system and emergency response mechanism for precise control throughout the discharge process.

4.1 Compliance Monitoring and Dynamic Adjustment

The effluent compliance monitoring system requires a multi-level monitoring network. An online monitoring station measuring six parameters (COD, NH_3-N, TP, TN, pH, turbidity) is installed at the final discharge outlet, with a sampling frequency set at every 2 hours. Data is transmitted in real-time via 4G network to the central control room and the environmental protection department's supervision platform. Monitoring equipment uses imported probes paired with domestic integrated systems, calibrated weekly with standard solutions and maintained monthly, ensuring data accuracy deviation is controlled within 5%. A neural network-based water quality prediction model is established. Inputting water quality data, meteorological data, and production load data from the previous 7 days predicts trends for the next 24 hours. When predicted values approach 80% of the discharge limits, the system automatically initiates enhanced treatment protocols: increasing aeration by 10-20%, raising the sludge recirculation ratio to 150%, and extending hydraulic retention time by 2-4 hours [4].

4.2 Ecological Buffering and Risk Prevention/Control

The ecological buffering system adopts a hybrid constructed wetland design: the front section is a vertical flow wetland, the middle section a horizontal subsurface flow wetland, and the rear section a surface flow wetland. The total hydraulic loading rate is controlled at 0.05-0.1 m^3/(m^2·d), with a hydraulic retention time of 48-72 hours. The wetland substrate uses a mixture of gravel (5-10 mm particle size), zeolite, and ceramsite filler in a 4:3:3 ratio, with a depth of 1.2-1.5 m. Local aquatic plants like reeds (Phragmites), cattails (Typha), and cannas (Canna) are planted at a density of 16-25 plants/m^2, with root depths reaching over 80% of the substrate layer. Emergency storage tanks are constructed of reinforced concrete, consisting of two independent tanks serving as mutual backups, each with a capacity ≥2000 m^3. Internal walls are coated with anti-corrosion paint, and submersible pumps and mixers are installed. The tanks are interlocked with the wastewater treatment system; when online monitoring data exceeds limits or equipment failure alarms occur, valves automatically switch to divert effluent into the emergency tanks for temporary storage.

4.3 Reclaimed Water Recycling and Resource Utilization

The reclaimed water reuse system is designed based on the principle of "quality-based supply and cascaded utilization". Reclaimed water is classified into three grades: Grade I (conductivity <200 μS/cm) for boiler feed and pure water preparation; Grade II (200-800 μS/cm) for recirculating cooling system makeup; Grade III (800-1500 μS/cm) for toilet flushing and landscape irrigation. The reclaimed water pipeline network uses ductile iron pipes with a design pressure of 0.6 MPa. Pipe diameters are calculated based on water demand (main pipes: DN300-400mm, branch pipes:

DN100-200mm). Flow meters and pressure gauges are installed along the route, with access valves and air release valves every 500m [5]. Water quality monitoring points and chlorine dosing devices are installed at each usage point to maintain a residual chlorine level of 0.2-0.5 mg/L at pipe ends, preventing microbial growth. A reclaimed water dispatch center is established to develop 24-hour supply schedules based on enterprise production plans and water demand, achieving constant pressure supply via variable-frequency pump groups (maintained at 0.35-0.45 MPa). A tiered pricing system is implemented for major water users: consumption up to 1000 tons/month is charged at 60% of the freshwater price, with excess charged at 40%. This economic leverage aims to promote reclaimed water utilization rates exceeding 70%.

4.4 Smart Management and Operational Assurance

The smart water platform adopts a distributed architecture. The data acquisition layer gathers signals from field instruments via PLCs and RTUs. The transmission layer uses industrial Ethernet and 5G networks for data transfer. The application layer deploys SCADA, GIS, expert diagnostic systems, and mobile apps, enabling collaborative management on PCs and mobile devices. Vibration sensors, temperature sensors, and current transformers are installed on critical equipment. Data is pre-processed via edge computing gateways. Early warnings are issued when operating parameters deviate from normal ranges, pushing alerts to operators' mobile apps requiring response within 30 minutes. Full lifecycle management records are maintained for equipment, documenting procurement, installation, commissioning, operation, maintenance, and disposal data. Preventive maintenance plans are formulated based on operating hours and failure frequency. Key equipment like blowers and pumps undergo maintenance every 2000 hours; membrane modules undergo chemical cleaning every 3 months [6]. The operations team is configured with 2 process engineers, 1 electrical engineer, 1 instrumentation engineer, and 8 operators, working under a three-shift system with two operational rotations to ensure 24/7 coverage. 119 standardized operating procedures (SOPs) and 42 emergency response plans are established, with quarterly emergency drills conducted.

5. Conclusion

The scientific design of industrial park wastewater treatment projects and the optimization of effluent discharge are vital safeguards for achieving sustainable park development. Through optimized whole-process design encompassing quality-based segregation, precise pretreatment, robust biological treatment, and deep purification, combined with comprehensive management strategies integrating smart monitoring, ecological buffering, and resource utilization, water resource recycling can be maximized while ensuring compliant discharge. Future efforts should continue to strengthen technological innovation and management optimization, driving industrial park wastewater treatment towards greater efficiency, economy, and ecological sustainability, contributing to the construction of a Beautiful China and the realization of carbon neutrality goals.

References

[1] Song Haoliang. Key Design Points of a Wastewater Treatment Plant Project in an Industrial Park in Guangdong[J]. Industrial Microbiology, 2025, 55(04): 226-228.

[2] Wang Weihong, Ran Lijun, Yang Jintao, et al. Current Status and Recommendations for Wastewater Control in Industrial Park Wastewater Treatment Plants in China[J]. Chinese Journal of Environmental Engineering, 2025, 19(07): 1619-1626.

[3] Kuang Yangduo. Industrial Park Wastewater Treatment Project Design and Effluent Discharge Optimization[J]. Water & Wastewater Engineering, 2025, 61(07): 82-88.

[4] Yuan Zhiming, Li Xing, Shen Jun, et al. Design Example of a Wastewater Treatment Project in an Industrial Park in Shandong[J]. Industrial Water & Wastewater, 2024, 55(04): 87-90+95.

[5] Cao Wenping, Zong Wei, Qian Hao, et al. Study on Combined Advanced Treatment Process for Effluent from an Industrial Park[J]. Journal of Xuzhou University of Technology (Natural Science Edition), 2023, 38(04): 77-80.

[6] Bai Xiaofei, Liu Honglei, Zhou Bin. Research on Industrial Park Wastewater Discharge Model Based on Game Theory — Taking the Central Area of Tianjin Economic-Technological Development Area as an Example[J]. Tianjin Science & Technology, 2018, 45(06): 91-94.