Design and Optimization of Industrial Park Wastewater Treatment Projects and Effluent Discharge

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Abstract: This paper systematically examines the necessity of constructing wastewater treatment projects from three dimensions: policy compliance, resource recycling and cost optimization. It explains important engineering design points, such as quality-based separate collection and source reduction; precise configuration of pretreatment units; biochemical system shock resistance design and modular reservation in an advanced treatment. In addition, four optimization strategies are proposed: dynamic adjustment compliance monitoring of effluent discharge, ecological buffering and risk prevention/control, reclaimed water recycle and resource utilization, smart management for operational assurance. The objective was to serve as a technical reference for industrial parks so that wastewater treatment systems can be constructed efficiently and through higher degrees of water 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 is promoted, industrial wastewater discharge standards keep increasing. Parks, as hotspots of pollution, are subject to enormous pressure from the environment; without appropriate treatment facilities, the park will directly affect the normal operation of enterprises and the attraction of investment. The condition of limited water supply has been a hurdle that lags industrial growth. The information given focuses on the premise that deep treatment and utilization of resources can produce an interdependent cycle involving a "water intake - water use - wastewater discharge - reclaimed water" process, while minimizing reliance on freshwater resources [1]. Centralized treatment facilities allow for concentrated control and large-scale management of pollutants, thus preventing redundant investments and management chaos caused by fragmented enterprise efforts. In addition, professional operation and management can carry on the stable treatment performance and provide a solid guarantee for industrial upgrading and green development in the park.

3. Key Points of Industrial Park Wastewater Treatment Project Design

Systematic design and refined management are the core of industrial park wastewater treatment

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engineering, which is a systematic project requiring full consideration along the water chain from waste water production to collection, treatment and discharge.

3.1 Quality-Based Separate Collection and Source Reduction

The systematic planning of the pipeline network design is necessary for quality-based separate collection of industrial park wastewater. In the first phase of the park, specially designed collection pipelines are prepared beforehand according to resident enterprise types. Take the wastewater of electroplating workshop with chromium, nickel extract(ord) to be collected through special pipeline and then input into chemical precipitation tank. Sodium sulfide or sodium hydroxide is added to make heavy metals into precipitates for elimination. The supernatant produced is then blended with other manufacturing wastewater in a complete equalization basin [2]. This volume is generally sized to contain 8-12 hours of average flow, based on shift volumes and discharge patterns of park businesses. Submersible mixers are installed to ensure solids deposition is avoided, and an automatic pH adjustment system keeping influent pH values between 6.5 and 8.5 is implemented. It establishes the discharge ledger of each enterprise by installing electromagnetic flow meters and online water quality monitoring instruments. Automatic valve closure at the source is applied to limit the total pollutant load from enterprises exceeding discharge limits.

3.2 Precise Configuration of Pretreatment Units

Selection of pretreatment processes should be based on comprehensive water quality analysis data. By continuous monitoring for 1 month to optimize the treatment train, variation patterns of indicators such as COD, BOD, ammonia nitrogen and total phosphorus are acquired. The Fenton oxidation reactor design must have well-controlled reaction conditions: pH adjusted to 3-4, ferrous sulfate and hydrogen peroxide dosed according to COD removal criteria (with molar ratios controlled between 1:5-10), and reaction time of 60-90 minutes. Aeration system promotes mass transfer, providing enough hydroxyl radicals produced and reacting with organics. DAF is chosen with recirculation ratio of 30-40% and saturation pressure of 0.3–0.4 MPa. Word count: POLYALUMINUM CHLORIDE (PAC)Polyacrylamide 100 mlBefore being introduced into the water source, PAC and PAM used for coagulant efficiency whole machine power fflocculant respectively, with dosages determined by jar tests (typically PAC: 50-100 mg/L, PAM: 1-3 mg/L). Coagulation-flocculation-sedimentation is performed in a mechanically mixed clarifier, which includes mixing zone, reaction zone and settling zone. Time of mixing 1-2 min, reaction time 15–20 min and the surface loading rate is controlled in a range of 1.5-2.5 $m^3/(m^2 \cdot h)$ to get out wastewater turbidity less than 20 NTU.

3.3 Shock Resistance Design of Biochemical System

Diversity of microbial community and system buffering capacity determine the shock resistance of biochemical system. Anaerobic reactors are internal circulation or upflow reactor types, formed by volumetric loading rates regulated at 5–8 kg COD/$(m^3 \cdot d)$. Three-phase separation Internally bio::gas-liquid-solid separation and maintaining the sludge concentration at 20–30 g/L in aerobic tank; Aeration technology step-feed aeration: influent distribute to multiple points on the front and middle sections of the aerobic tank. In this case, fine bubble diffusers are selected with the target of obtaining oxygen transfer efficiencies greater than 25%. Variable-frequency blowers are designed to control aeration based on dissolved oxygen concentration levels. There are two crucial parameters in this regard, the sludge recirculation ratio (SRR) should be maintained at 50–100% and mixed liquor recirculation ratio (MLR) of 200–400% to allow microbes loaded within system [29]. The emergency dosing system is located beside the biochemical tanks and owns carbon sources (for example, glucose or methanol) and phosphate nutrients. These are supplemented rapidly when imbalanced influent C/N ratio occurs, in agreement with the desired (COD:N:P) nutrients composition of 100:5:1.

3.4 Advanced Treatment and Reuse Reservation

The improved treatment system employs a multi-barrier design philosophy. Initial treatment involves suspension of solids through multi-media filters, followed by activated carbon adsorption of soluble organics and color. Final deep purification is provided with membrane separation systems.

Ultrafiltration (UF)The machine uses polyvinylidene fluoride (PVDF) hollow fiber membranes with pore sizes of 0.01–0.1 μm, a pressure range at 0.1–0.3 MPa fixed flux at 60–80 L/(m^2·h), and regular backwashing (5-8% of the permeate volume used in cleaning every during every step of 30 – 40 minutes). The two-stage/two-pass reverse osmosis (RO) configuration. The first stage with a system recovery of 75% reaches salt rejection greater than 97%. In the second-stage RO, the brine is pressurized by a high-pressure pump [3]. Membrane units are modular with a single module size of 500 m^3/d capacity, however only 60% of this capacity is installed initially while pipeline and electrical interfaces are reserved for when additional flow warrants fast-tracked expansion. Collectively, permeate can be harvested by conductivity grades as follows: 1) <100 μS/cm for makeup of boiler feed water; 2): 100--500 μS/cm for recirculating cooling water make-up; and3) 500--1000 and≥1000μS/cmforspreading in landscape or road cleaning with a dedicated reclaimed water distribution network to each demand-use point.

4. Optimization Strategies for Industrial Park Wastewater Effluent Discharge

Optimizing the surface water discharge of effluent is critical to long-term stable operation of a wastewater treatment system, whole-process monitoring system and emergency response mechanism are required for precise control over the discharge process.

4.1 Compliance Monitoring and Dynamic Adjustment

Monitoring network at multi-level to establishing effluent compliance monitoring system. An online monitoring station with six parameters (COD, NH -N, TP TN, pH turbidity) is arranged at the terminal discharge outlet, and every 2 hours its sampling frequency is measured. The 4G network transmits data in real time to the central control room and monitoring platform of environmental supervision department. The monitoring equipment is comprised of imported probes used with domestic integrated systems, which undergoes weekly calibration to standard solution as well as a monthly maintenance regimen and maintains data accuracy deviation at 5% or less. A water quality prediction model is built using a neural network. For every 24 hours, trends are predicted based on water quality from the input data as well as the meteorological data and production load for this in a week prior to this. If predicted values come within 80% of the discharge limits, automatic monitoring protocols engage first-rate measures: aeration is raised by 10 ~ 20%, sludge recirculation ratio to 150%, and hydraulic retention time extended by two to four hours [4].

4.2 Ecological Buffering and Risk Prevention/Control

The ecological buffering system uses a hybrid constructed wetland approach consisting of a vertical flow wetland at the front, horizontal subsurface flow wetland in the middle and surface flow at the rear. The total hydraulic loading rate for the system is controlled at 0.05-0.1 m^3/(m^2·d) with a hydraulic retention time of 48–72 h. The wetland substrate is filled with a mixture of gravel (5-10 mm particle size), zeolite, and ceramsite in a ratio of 4:3:3 with a depth of 1.2–1.5 m, local aquatic plants such as reeds (Phragmites), cattails (Typha) and cannas (Canna) are planted at a density of 16–25 plants/m^2having root depths exceeding 80% of the substrate layer depth. Emergency storage tanks are presented with two identical reinforced concrete tanks serving as redundancy to each other, immediately adjacent with a volume of ≥2000 m^3. They have anti-corrosion paint on internal walls, submersible pumps and even mixers. The tanks link to the wastewater treatment system; when online monitoring readings are abnormal or equipment failure alarms trigger, valves automatically switch to direct effluent into the emergency tanks for temporary holding.

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. Ductile iron pipes with a design pressure of 0.6 MPa are used for the reclaimed water pipeline network. Pipe diameters usually depend on the water demand, main pipes: DN300-400mm; branch pipes: DN100-200 mm Flow meters and pressure gauges are placed throughout the course, with access valves every 500m [5]. Water quality monitoring points and chlorine dosing devices are placed in every usage point to achieve a residual chlorine concentration of 0.2–0.5 mg/L at the outlet ends of pipes, preventing microbial growth. The system builds a reclaimed water dispatch center to formulate 24 h supply schedules based on enterprise production plans and water demand, achieving constant pressure supply through variable-frequency pump groups (0.35–0.45 MPa maintained). Furthermore, a tiered pricing system was applied for the major water users: consumption of up to 1000 tons/month is charged at 60% of the freshwater price, while excessive consumption is charged at 40%. With this economic leverage, it aims to achieve more than 70% utilization rates of reclaimed water.

4.4 Smart Management and Operational Assurance

Smart Water Platform — A distributed architecture. The data acquisition layer acquires these signals from the field instruments, using PLCS and RTUS. Data transmission between units is managed on industrial Ethernet and cellular 5G networks, forming the data transmission layer. SCADA, GIS, and expert diagnostic systems are deployed at the application layer mobile apps which provide collaborative management on both PCs and mobile devices. Sensors for vibration, temperature and current transformers are installed on key equipment. Edge computing gateways pre-process the data. You get early warnings when operating parameters start straying outside the normal ranges and alerts are pushed to operators' mobile apps requiring a response within 30 minutes. It keeps full lifecycle management records for any particular piece of equipment, including procurement and installation, commissioning, operation data and maintenance data along with disposal. From the operating hours and periodicity of failures you create plans of preventive maintenance. Maintenance is performed on key equipment such as blowers and pumps after every 2000 hours, while membrane modules undergo chemical cleaning after every 3 months [6]. The operations team consists of 2 process engineers, 1 electrical engineer, 1 instrumentation engineer and 8 operators who work in a three-shift system with two operational rotations ensuring continuous round-the-clock coverage (24 hours/7 days). Quarterly emergency drills are conducted and 119 standardized operating procedures (SOPs) are established along with 42 emergency response plans.

5. Conclusion

Industrial park wastewater treatment projects have the characteristics of low water volume, long detention time and weak biodegradability, which has a great impact on surface water if discharged without treatment. Optimized whole-process design, which includes quality-based segregation, precise pretreatment, robust biological treatment and deep purification can lead to comprehensive water resource recycling with compliant discharge by adaptive management strategies of smart monitoring, ecological buffering and resource utilization. To improve the technological innovation and management optimization of industrial park wastewater treatment towards greener, lower-carbon and economically sustainable in the future, thus promoting the construction of a Beautiful China and achieving carbon neutrality goals.

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