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Safety Operation Management and Optimization Strategies for Desulfurization and Denitrification Facilities

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Abstract: This study addresses safety risks in the operation of flue gas desulfurization and denitrification facilities. Key points for safe operation management are clarified from four aspects: full lifecycle equipment management, operational parameter monitoring, medium control, and personnel training. Furthermore, five optimization strategies are proposed: process parameter optimization, intelligent monitoring upgrades, equipment retrofitting, operation and maintenance innovation, and multi-system coordination. These measures aim to enhance operational safety and efficiency, reduce failure risks, and provide support for the long-term stable operation and green development of industrial flue gas treatment systems.
Keywords: Flue gas desulfurization and denitrification facilities; safe operation management; equipment monitoring; process optimization; intelligent operation and maintenance

Introduction

In industrial production, flue gas desulfurization and denitrification (FGD/DeNOx) facilities play a critical role in controlling pollutant emissions from flue gas. However, factors such as equipment aging, lagging monitoring, and non-standardized operation and maintenance pose challenges to their safe operation, and may also lead to environmental and personnel safety hazards. Strengthening the safe operation management of these facilities and exploring scientific optimization strategies are not only essential measures for ensuring production safety but also key to achieving compliant emissions and improving corporate environmental performance. These efforts are of significant importance in promoting green and sustainable industrial development. The following sections provide a detailed analysis.

1. Operational Status and Safety Risk Analysis of Desulfurization and Denitrification Facilities

Currently, desulfurization and denitrification systems applied in the industrial sector mainly include wet flue gas desulfurization (WFGD), dry desulfurization, selective catalytic reduction (SCR) denitrification, and selective non-catalytic reduction (SNCR) denitrification. Each process type exhibits different operational characteristics and safety risks. Overall, many facilities face issues such as equipment aging and wear, delayed monitoring data, and non-standardized operation and maintenance procedures, all of which increase the risk of unsafe operation. For example, blockage or damage of the spray devices inside a desulfurization tower can lead to reduced desulfurization efficiency and may further cause abnormal tower pressure. In denitrification systems, if the catalyst activity decays and is not detected in time, not only will denitrification efficiency decline, but excessive reductant consumption and secondary pollution may also occur. In addition, media involved in the operation process—such as ammonia water and liquid ammonia—pose safety threats to personnel and the surrounding environment if leaks occur during storage or transportation. Therefore, a thorough analysis of the safety risks associated with desulfurization and denitrification facilities is a prerequisite for formulating effective management and optimization strategies [1].

2. Key Points in the Safe Operation Management of Desulfurization and Denitrification Facilities

2.1 Equipment Lifecycle Management

Equipment constitutes the foundation of safe operation for desulfurization and denitrification systems. A comprehensive lifecycle management system covering procurement, installation, operation, maintenance, and decommissioning is required.

Procurement stage: Equipment selection should match process requirements and operating environments, prioritizing stable and energy-efficient devices to ensure reliability from the source.

Installation stage: Technical specifications must be strictly followed, with a focus on installation accuracy and sealing performance to ensure proper system compatibility.

Operation stage: A standardized inspection regime should be established, defining inspection items and frequencies for key equipment such as fans, pumps, heat exchangers, and catalyst reactors. Real-time recording of operational parameters is essential for capturing anomalies in a timely manner.

Maintenance stage: Maintenance schedules should be developed based on wear patterns, including routine lubrication, cleaning, and replacement of components. A reserve inventory of consumable parts—such as seals and filters—helps reduce repair downtime.

Decommissioning stage: Retired equipment should be disposed of in compliance with environmental regulations. Meanwhile, lifecycle data should be summarized to inform future equipment selection and management strategies.

2.2 Real-Time Monitoring and Control of Operational Parameters

Operational parameters directly determine the safety and treatment efficiency of desulfurization and denitrification facilities. A comprehensive real-time monitoring system is required to achieve dynamic control. For desulfurization systems, key monitored parameters include the inlet and outlet flue gas temperature, pressure, flow rate, SO_2 concentration, absorbent slurry concentration, pH value, liquid level, and circulation pump operating parameters. For denitrification systems, monitoring focuses on the inlet and outlet flue gas temperature, NO_x concentration, oxygen content, reductant injection rate and pressure, and catalyst bed temperature. The monitoring system should integrate data acquisition, storage, analysis, and early-warning functions. When parameters exceed threshold values, audible and visual alarms should be automatically triggered, and manual or automatic adjustments should be supported. For example, adjust the cooling devices when the flue gas at the desulfurization tower inlet exceeds the temperature limit, and precisely regulate the reductant injection rate when NO_x emissions in the denitrification system exceed the standard. At the same time, regularly calibrate sensors and inspect data transmission lines and control systems to ensure monitoring data accuracy, providing a reliable basis for process control [2].

2.3 Safe Management of Operating Media

For media used in desulfurization and denitrification systems, such as limestone slurry, gypsum slurry, ammonia water, liquid ammonia, and urea solution, full-process safety management is required.

Storage: Facilities must be designed according to media properties. Liquid ammonia should be stored in sealed pressure vessels equipped with fire- and explosion-proof ventilation and leakage detection systems. Ammonia water tanks should be treated for corrosion resistance.

Transportation: Appropriate pipelines and valves should be selected, with regular inspection of sealing performance. Transfer pumps should include overload protection to prevent interruption or leakage.

In addition, a leakage emergency response plan should be developed, specifying handling procedures, personnel responsibilities, and protective measures, with regular drills conducted. A procurement, storage, and usage ledger should be maintained to ensure traceability, prevent waste, and avoid improper handling.

2.4 Personnel Operation and Safety Training

Personnel competency is critical to safe operation and requires a "qualification–training–assessment" management system. A strict qualification system should define the responsibilities and skill requirements for operation and maintenance personnel. New employees may only operate independently after completing systematic pre-job training and passing assessments. Regular on-the-job training should cover technical skills (process principles, equipment operation, parameter adjustment, fault diagnosis) and safety knowledge (media properties, leakage response, fire safety, and protective equipment use). Training should include theoretical instruction, on-site practice, and case analysis to ensure effectiveness. An assessment and incentive system should be implemented, incorporating operational compliance, inspection quality, and emergency response capability. Rewarding excellence and addressing deficiencies will strengthen responsibility awareness and foster a professional and competent O&M team.

3. Optimization Strategies for Safe Operation of Desulfurization and Denitrification Facilities

3.1 Process Parameter Optimization and Adaptive Control

Based on the operational characteristics and treatment requirements of desulfurization and denitrification facilities, process parameter optimization research can be conducted using real-time monitoring data and historical operation data, and parameter optimization models can be established to enable adaptive process control, effectively improving operational safety and efficiency.

(1) **Desulfurization Process Parameter Optimization:** Optimize operation parameters according to dynamic changes in inlet SO_2 concentration and flue gas flow through experiments and simulation analyses. When inlet SO_2 concentration is high, increase the pH of the absorbent slurry and the number of circulating pumps to enhance desulfurization reactions; when the concentration is low, reduce slurry concentration and pump operation to save energy and absorbent. Numerical simulations and on-site testing can also optimize airflow distribution and spray layout inside the desulfurization tower, adjusting spray layer height, nozzle number, and angles to improve gas–liquid contact, prevent local short-circuiting or slurry accumulation, and reduce equipment clogging and corrosion risks.

(2) **Denitrification Process Parameter Optimization:** Combine inlet NO_x concentration, flue gas temperature, and oxygen content to optimize reductant injection volume and position, establishing a correlation model for precise dosing to avoid excessive ammonia slip or insufficient denitrification. For SCR systems, optimize reactor inlet temperature according to catalyst activity variation, maintaining optimal temperature ranges; when catalyst activity declines, adjust flue gas preheating to stabilize temperature and prolong catalyst life. The optimized parameter models can be embedded into the monitoring system, using adaptive control algorithms for automatic adjustment, ensuring safe and efficient operation under fluctuating conditions [3].

3.2 Intelligent Monitoring and Early Warning System Upgrade

(1) **Sensor Network Enhancement:** Install high-precision sensors at critical points: corrosion sensors on desulfurization tower walls for real-time structural monitoring, temperature and pressure sensors on denitrification catalyst beds to capture catalyst operational data, and leakage sensors along media storage tanks and pipelines for early detection. Wireless sensor technology and edge computing devices address the complexity and data latency issues of traditional wired systems, enhancing real-time data acquisition and flexibility.

(2) **Big Data Analysis Platform Construction:**

Integrate equipment operation parameters, media properties, environmental data, and maintenance records. Perform data cleaning, fusion, and mining to analyze correlations, identify abnormal patterns, and detect potential risks—for example, using fan vibration and runtime data to predict bearing remaining life, or combining ammonia slip, catalyst activity, and reductant injection data to determine if the catalyst requires regeneration.

(3) **AI-Based Risk Prediction:** Introduce neural networks, support vector machines, and other AI algorithms to build a risk early warning model predicting fault type, location, and timing. When risks are detected, the system automatically triggers warnings and sends mitigation recommendations to operation terminals. Integrating the intelligent platform with enterprise production management systems enables data sharing and coordinated management, supporting production scheduling and safety management.

3.3 Equipment Energy Saving and Reliability Enhancement

Based on current operation and technology trends, retrofit existing equipment to reduce energy consumption, minimize failures, and extend service life:

(1) **Fan Upgrades:** For high-power fans like induced draft and booster fans, use variable frequency drives (VFDs) instead of traditional damper control to adjust speed according to flue gas flow, reducing energy consumption and start-stop wear. Replace outdated low-efficiency fans with high-efficiency models, optimizing impeller structure and motor performance to improve efficiency and stability.

(2) **Pump Upgrades:** Upgrade desulfurization slurry circulation pumps and absorbent delivery pumps with high-efficiency hydraulic models to reduce hydraulic losses. Replace packing seals with mechanical seals to minimize leakage, media loss, and maintenance requirements.

(3) **Heat Exchanger Upgrades:** Use high-efficiency elements like spiral plate or plate-and-shell heat exchangers to increase heat transfer area. Apply anti-corrosion coatings to surfaces to enhance durability.

(4) **SCR Catalyst Optimization:** Employ new high-efficiency honeycomb or plate catalysts to improve activity and selectivity, reducing usage and costs. Optimize reactor structure to ensure uniform flue gas flow, avoiding local wear or dust accumulation and enhancing catalyst utilization. Monitoring and fault diagnosis technologies can track operational status, evaluate retrofit effectiveness, and provide references for future upgrades [4].

3.4 Operation and Maintenance Innovation and Digital Management

(1) **Implement Predictive Maintenance:** Relying on equipment operational data collected by intelligent monitoring systems and analyzed through big data, predict potential equipment failures and formulate maintenance plans in advance. This replaces traditional scheduled preventive maintenance, reduces unnecessary maintenance operations to lower costs, and prevents failures caused by delayed maintenance. For example, analyzing vibration spectra of pumps can forecast bearing failure timing, allowing for early replacement and avoiding sudden pump failures that could disrupt facility operation.

(2) **Establish a Digital O&M Management Platform:** Integrate equipment ledgers, maintenance records, fault reports, spare parts inventory, and personnel scheduling into a centralized platform for management and data sharing. The platform supports maintenance planning, task assignment, process tracking, and effectiveness evaluation. Operation personnel can receive tasks and log outcomes, while managers monitor progress in real time, optimizing resource allocation to improve efficiency.

(3) **Introduce Mobile and Remote O&M Technologies:** Equip operation personnel with smart devices such as smartphones and tablets. When connected to the digital platform, they can access equipment information, maintenance manuals, and fault-handling procedures in real time, while recording operational and maintenance data on site. This enables real-time on-site management and information synchronization, reducing transmission delays and speeding up response. Additionally, for geographically dispersed or harsh-environment facilities, remote monitoring and diagnostic systems can track status and guide fault handling, reducing on-site difficulty and risk, expanding coverage, and enhancing timeliness.

3.5 Coordinated Multi-System Optimization and Overall Performance Enhancement

(1) Establish a multi-system data sharing mechanism

by integrating operational data from desulfurization and denitrification systems with boiler combustion, dust removal, and induced draft fan systems. Through data interaction and analysis, identify interrelated influences, such as flue gas parameter fluctuations caused by boiler load changes or the effect of induced draft fan status on flue gas pressure. Based on data sharing, achieve coordinated parameter adjustments: when boiler load increases, proactively adjust the consumption of absorbents and reductants as well as fan operation status to ensure desulfurization and denitrification efficiency; in the event of induced fan failure, promptly adjust facility load to avoid abnormal flue gas pressure.

(2) Optimize the operational sequence of multiple systems by considering production load and environmental requirements, and reasonably plan the startup and shutdown order and operational modes. During startup, initiate the induced draft system first to ensure smooth flue gas channels, followed by the desulfurization, denitrification, and boiler systems. During shutdown, gradually reduce boiler load, then decrease absorbent and reductant supply, and finally stop the induced draft system, avoiding emissions exceeding standards or equipment damage caused by improper sequencing.

(3) Construct a comprehensive performance evaluation system for multiple systems, covering indicators such as pollutant removal efficiency, energy consumption, water usage, and equipment reliability. Regularly assess the effectiveness of coordination, identify issues such as data transmission delays or asynchronous parameter adjustments, and enhance system stability, safety, and economic efficiency by optimizing transmission networks and improving control algorithms, achieving efficient and environmentally friendly flue gas treatment operations.

Conclusion

The safe operation management of desulfurization and denitrification facilities requires multidimensional control of equipment, parameters, media, and personnel, while optimization strategies must integrate technological innovation and system coordination. By implementing key management measures and optimization strategies, operational risks can be effectively reduced, and efficiency and reliability enhanced. With the advancement of technology, future management and optimization efforts will become more precise and efficient, playing a critical role in helping industrial enterprises achieve coordinated environmental protection and production, and promoting sustainable green and low-carbon development.

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