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Research on Intelligent Coupling SNCR/SCR Denitrification Technology for Thermal Power Station Boilers Based on Artificial Intelligence

Chunguang Zhou [1], Hao Yu [1], Shunguo Cai [1], Hongming Qiu [1], Zhiqiang Chen [2], Gang Huang [2]

[1] Quzhou Donggang Environmental Protection Thermal Power Co., Ltd. Zhejiang, 324022, China
[2] College of Electrical and Information Engineering, Quzhou University, Quzhou 324000, China

Abstract: This study presents an exploration of the implementation of intelligent coupling SNCR/SCR denitrification technology for thermal power station boilers, addressing the global imperatives of carbon peaking and carbon neutrality. By leveraging artificial intelligence (AI) techniques and advanced control strategies, the project has developed an innovative technical solution that integrates multi-objective optimization algorithms, data-driven predictive models, and fuzzy control algorithms. This solution not only tackles the complexities inherent in the denitrification process but also optimizes operational efficiency and reduces environmental impact. The technology is expected to significantly reduce nitrogen oxide (NOx) emissions, meeting or exceeding national environmental standards, while yielding substantial economic benefits through optimized ammonia consumption and reduced operational costs. Furthermore, the integration of intelligent control strategies enhances operational stability and reliability. Future prospects for the technology include the exploration of advanced AI techniques, integration with the Internet of Things (IoT) and big data analytics, efforts towards standardization and scalability, collaboration with policymakers and regulatory bodies, and raising public awareness. The intelligent coupling SNCR/SCR denitrification technology represents a significant step towards achieving carbon peaking and carbon neutrality goals, with immense potential to transform the thermal power industry.

Keywords: Denitrification technology, Thermal power station boilers, Multi-objective optimization, Operational stability, Carbon neutrality.

1. Introduction

1.1. Research Background and Significance

With the global emphasis on achieving carbon peaking and carbon neutrality, the thermal power industry, as a major energy-consuming sector, faces increasing pressure to reduce emissions and enhance energy efficiency. In response to this, the Chinese government has issued a series of policies to guide the energy-saving and carbon-reduction transformation and upgrading of high-energy-consuming industries, including thermal power stations. To meet the stringent environmental protection requirements and promote sustainable development, it is imperative to develop advanced denitrification technologies for thermal power station boilers.

Selective Non-Catalytic Reduction (SNCR) and Selective Catalytic Reduction (SCR) are currently the mainstream denitrification technologies employed in coal-fired power plants, accounting for over 99% of denitrification applications in thermal power units. However, traditional SNCR and SCR technologies have limitations in terms of efficiency, cost, and adaptability to varying operating conditions. Therefore, research on intelligent coupling SNCR/SCR denitrification technology, driven by artificial intelligence, has emerged as a promising solution to achieve ultra-low nitrogen oxide (NOx) emissions, energy conservation, and efficiency improvement.

The proposed research project, entitled "Research on Intelligent Coupling SNCR/SCR Denitrification Technology for Thermal Power Station Boilers Based on Artificial Intelligence," aims to develop a smart denitrification system that leverages advanced algorithms and predictive models to optimize the operation of SNCR/SCR processes. This technology not only addresses the technical challenges faced by traditional denitrification methods but also aligns with the global trend towards green and intelligent production. By achieving ultra-low NOx emissions and reducing operational costs, the project contributes significantly to improving air quality and meeting national environmental protection standards.

1.2. Domestic and International Research Status

Globally, there has been extensive research on improving the efficiency and cost-effectiveness of denitrification technologies for thermal power stations. The integration of artificial intelligence, particularly machine learning and predictive modeling, has shown promising results in optimizing the operation of SNCR/SCR systems. Intelligent control strategies, such as iFOC (Intelligent Fluent Oxidation Control), have been developed to enhance the precision and adaptability of denitrification processes. These strategies employ advanced control algorithms to dynamically adjust operational parameters based on real-time data, thereby improving denitrification efficiency and reducing ammonia slip.

In China, policies such as the "Guidance for Energy-Saving and Carbon-Reduction Transformation and Upgrading in Key Areas of High-Energy-Consuming Industries" and the "Implementation Plan for Carbon Peaking in Industrial Sectors in Zhejiang Province" have accelerated research and development in this field. Many enterprises and research institutions have focused on improving the performance of SNCR/SCR systems through technological innovations and intelligent upgrades. However, there remains a need for further research to address the challenges of maintaining system stability, improving control accuracy, and reducing operational costs under varying load conditions and fuel properties.

The current research project builds upon the existing literature and practical experience to develop an intelligent coupling SNCR/SCR denitrification technology tailored for Chinese thermal power station boilers. By incorporating advanced artificial intelligence techniques, this project aims to overcome the limitations of traditional denitrification methods and contribute to the green and sustainable development of the thermal power industry.

2. Analysis of Project Foundation Conditions

2.1. Existing Research and Development Basis

The proposed research project is based on a solid foundation of existing research and development efforts in the field of intelligent denitrification technologies for thermal power station boilers. The project team comprises researchers from both industry and academia, each with strong research and development capabilities. The project is supported by a leading public cogeneration enterprise in Quzhou City, which has a long history of providing electricity and heat to various industrial users within its supply area.

The project team has conducted extensive research on SNCR/SCR denitrification technologies and has accumulated significant experience in upgrading and retrofitting denitrification systems. Previous projects have involved the optimization of spray guns, modification of ammonia water pumps, and the integration of intelligent control systems. These efforts have laid a solid technical foundation for the current project, which aims to further enhance the efficiency and intelligence of the denitrification process.

2.2. Hardware and Data Resources

The project relies on a robust hardware infrastructure, including advanced detection and automation equipment, as well as a well-established production data center. The data center supports the transmission, storage, and computation of large volumes of production data, enabling the project team to leverage these data for predictive modeling and optimization.

The project also benefits from a rich source of historical data collected from various operating conditions of the thermal power station boilers. These data, when combined with real-time monitoring data, provide a comprehensive dataset for training and validating the predictive models developed in the project.

2.3. Human Resources and Expertise

The project team boasts a strong human resource base, comprising engineers with extensive practical experience in thermal power production and denitrification technologies. The team leader, with over 24 years of experience in thermal power plant project construction, technical improvement, and management, brings a wealth of knowledge and expertise to the project. Additionally, the team includes researchers from a provincial-level doctoral innovation station established in collaboration with local universities. This collaboration ensures access to cutting-edge research and technical support from academia.

The doctoral innovation station, which currently houses six doctoral supervisors (including two professors) and four master's degree holders, provides a fertile ground for fostering young talents and promoting innovation in the field of intelligent denitrification technologies. The team members are well-versed in system intelligence prediction, decision-making, and optimization, which are crucial for the success of the project.

2.4. Technological Prerequisites and Current Challenges

While the project has a solid foundation in terms of hardware, data, and human resources, it also faces several challenges. One of the primary challenges is the need to maintain system stability while optimizing the denitrification process. The dynamic changes in load conditions and external environments require the control system to be highly adaptive and stable.

Another challenge lies in the integration and optimization of advanced control technologies, such as iFOC, with traditional PID control systems. This integration requires effective technical coordination and optimization to ensure the efficient operation of the control system.

Moreover, the project must address the limitations imposed by the working temperature range of catalysts used in SCR technology. Additionally, economic considerations and environmental regulations necessitate the development of cost-effective and environmentally friendly denitrification solutions.

In summary, the project foundation conditions are favorable, with strong support from industry, academia, and government. However, the project team must address several technical and operational challenges to successfully develop and implement the intelligent coupling SNCR/SCR denitrification technology for thermal power station boilers.

3. Technical Solution for the Project

3.1. Research Objectives

The primary objective of this project is to develop an intelligent coupling SNCR/SCR denitrification technology for thermal power station boilers. This technology aims to address the complex pollutant removal process, high system inertia, and delayed response of key operating parameters that currently hinder the effective control and management of denitrification operations. By integrating artificial intelligence (AI) with traditional denitrification processes, the project aims to achieve ultra-low nitrogen oxide (NOx) emissions, energy conservation, and efficiency enhancement, thereby improving air quality and meeting national environmental protection requirements.

3.2. Main Research Contents

Research Content 1: Construction of Process Mechanism Optimization Model Based on Multi-Objective Optimization Algorithms

This research content focuses on the development of an optimization model for the SNCR/SCR coupling denitrification process. By leveraging multi-objective optimization algorithms, the model will be customized according to the specific hardware configuration of the boiler. The model will consider various factors such as catalyst selection, reaction temperature control, reductant selection and distribution, flow field distribution, system integration and control, and economic feasibility. By integrating AI prediction algorithms with process mechanism analysis, the model will be capable of self-learning and automatic updates, ensuring optimal performance under varying operating conditions.

Research Content 2: Data-Driven Predictive Model for NOx Emission Concentration

Based on extensive historical data collected from boiler operations, this research content aims to develop a predictive model for NOx emission concentration using advanced AI algorithms such as Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU). The model will incorporate real-time monitoring data on flue gas composition, temperature, pressure, and other relevant parameters. By analyzing these data, the model will be able to provide accurate predictions of NOx emission concentrations, enabling proactive control of ammonia injection and optimization of denitrification efficiency.

Research Content 3: Design of SNCR/SCR Denitrification Process Control Strategy Based on Fuzzy Control Algorithms

This research content focuses on the development of a control strategy for the SNCR/SCR denitrification process using fuzzy control algorithms. The strategy will take into account different load conditions and abnormal operating scenarios, and will leverage advanced automation and intelligent control technologies to achieve precise control of the denitrification process. By integrating predictive results with intelligent control strategies, the system will be able to adapt to dynamic changes in operating conditions, ensuring optimal NOx emission control and efficiency.

3.3. Key Technologies

Key Technology 1: Fine-Grained Injection of Catalysts and Reductants

This key technology addresses the precise control of reductant injection in both SNCR and SCR processes. By integrating advanced sensing technologies and flow field simulation, the system will be able to monitor and adjust flue gas temperature and flow field distribution in real-time, ensuring optimal reaction conditions. This will maximize denitrification efficiency while minimizing ammonia slip, promoting environmental friendliness and resource efficiency.

Key Technology 2: Self-Learning and Adaptive Optimization Control Strategy

This key technology enables the denitrification system to adaptively adjust its control parameters and strategies based on historical and real-time data. By leveraging big data analytics and machine learning algorithms, the system will be able to identify key factors affecting denitrification efficiency and their dynamic changes. This will enable the system to operate at optimal performance under varying load conditions and fuel properties, ensuring stable and reliable operation while meeting environmental regulations.

3.4. Overall Scheme and Technical Route

The project will follow a comprehensive scheme encompassing theoretical research, method development, and practical application. The technical route will involve experimental research, qualitative and quantitative analysis, model simulation, and case validation. By adhering to the principles of novelty and practicality in theoretical research, the project aims to produce research outcomes that can empower environmental engineering projects and drive the intelligent transformation of industrial denitrification processes. The project will leverage existing hardware and data resources to construct an AI platform for the development of optimization and predictive models, ultimately achieving precise control and efficient operation of the denitrification system.

3.5. Detailed Research Plan

Model Construction Based on Multi-Objective Optimization Algorithms: This plan involves collecting and preprocessing data related to various process parameters, extracting dominant features using principal component analysis, and constructing an optimization model using evolutionary algorithms and particle swarm optimization.

Data-Driven Predictive Model for NOx Emission Concentration: This plan involves real-time data acquisition and preprocessing, feature extraction using convolutional neural networks, model construction using LSTM/GRU, and integration with control systems for proactive adjustment of operating parameters.

Control Strategy Design Based on Fuzzy Control Algorithms: This plan involves defining input and output variables, fuzzy sets and membership functions, establishing fuzzy control rules, and incorporating feedback mechanisms and neural network algorithms to enhance system adaptability and robustness.

By implementing this technical solution, the project aims to develop an intelligent coupling SNCR/SCR denitrification technology that can significantly improve the efficiency and environmental performance of thermal power station boilers.

4. Project Implementation and Verification

4.1. Project Implementation Plan

The successful implementation of the project hinges on a well-structured and meticulously planned execution strategy. The following steps outline the key implementation phases:

Project Initiation and Team Formation:

Establish a dedicated project team comprising professionals from both the enterprise and the collaborating university.

Define project scope, objectives, and milestones.

Develop a detailed project schedule and resource allocation plan.

Data Collection and Preprocessing:

Utilize the existing DCS (Distributed Control System) to collect extensive historical data on boiler operations, including temperature, pressure, flow rates, fuel type, combustion efficiency, etc.

Conduct data cleaning, normalization, and preprocessing to ensure data quality and consistency.

System Upgrade and Equipment Installation:

Upgrade existing SNCR/SCR equipment as per the research requirements, including optimizing spray guns, modifying ammonia water pumps, and installing advanced sensors.

Develop and integrate a software control system to facilitate real-time data acquisition and control commands.

Model Development and Optimization:

Develop process mechanism optimization models using multi-objective optimization algorithms.

Construct data-driven predictive models for NOx emission concentration based on LSTM/GRU networks.

Design control strategies incorporating fuzzy control algorithms to adapt to varying load conditions and fuel properties.

System Integration and Testing:

Integrate the developed models and control strategies into the existing boiler control system.

Conduct rigorous testing under different operating conditions to validate the performance and reliability of the integrated system.

Pilot Deployment and Monitoring:

Deploy the upgraded system on a pilot boiler for real-world testing.

Continuously monitor system performance, adjust parameters as necessary, and gather feedback from operators.

Full-Scale Deployment and Optimization:

Roll out the system across all boilers in the thermal power station.

Conduct periodic system audits and optimizations to ensure sustained performance and compliance with environmental regulations.

4.2. Project Verification and Evaluation

To ensure the effectiveness and reliability of the proposed SNCR/SCR intelligent coupling denitrification technology, a comprehensive verification and evaluation plan is essential. The following steps will be taken:

Data Validation and Model Calibration:

Validate the accuracy of the collected data by comparing it against known benchmarks and industry standards.

Calibrate the developed models using real-time data from the pilot deployment to improve their predictive capabilities.

Performance Metrics and Benchmarking:

Define key performance indicators (KPIs) such as NOx emission reduction, ammonia consumption, system reliability, and operational costs.

Benchmark the performance of the upgraded system against the existing denitrification technology to demonstrate improvements.

Operational Efficiency and Economic Impact:

Evaluate the operational efficiency of the system in terms of reduced downtime, maintenance costs, and improved energy utilization.

Assess the economic impact by calculating cost savings from reduced ammonia consumption, improved fuel efficiency, and decreased regulatory fines.

Environmental Compliance and Sustainability:

Verify that the upgraded system meets or exceeds national and international environmental standards for NOx emissions.

Assess the long-term sustainability of the technology in terms of resource conservation, emissions reduction, and ecological impact.

User Feedback and Continuous Improvement:

Gather feedback from operators and maintenance personnel to identify areas for improvement.

Implement continuous improvement measures based on user feedback and technological advancements to ensure the system remains state-of-the-art.

By adhering to this structured implementation and verification plan, the project aims to successfully develop and deploy an intelligent coupling SNCR/SCR denitrification technology that significantly enhances the environmental performance and economic efficiency of thermal power station boilers.

5. Conclusion

The present study has conducted a thorough examination of the implementation of intelligent coupling SNCR/SCR denitrification technology for thermal power station boilers. Against the global backdrop of carbon peaking and carbon neutrality objectives, the development of this technology is crucial for mitigating nitrogen oxide (NOx) emissions and enhancing the environmental sustainability of thermal power generation.

Leveraging artificial intelligence (AI) techniques and advanced control strategies, the project has successfully achieved key objectives. An innovative technical solution, integrating multi-objective optimization algorithms, data-driven predictive models, and fuzzy control algorithms, has been developed. This solution effectively addresses the complexities of the denitrification process, optimizes operational efficiency, and reduces environmental impact. Notably, the technology is projected to significantly reduce NOx emissions, meeting or exceeding national environmental standards, thereby contributing to improved air quality and public health.

Economically, the technology is viable, promising substantial benefits for thermal power stations. By optimizing ammonia consumption and reducing operational costs, including maintenance expenses and regulatory fines, the technology is expected to yield cost savings. Furthermore, the integration of intelligent control strategies enhances the system's adaptability to varying load conditions and fuel properties, improving operational stability and reliability.

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