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Industrial Practices and Precise Control Technology of De-Nitration in Power Plant: Commercial Strategy Approach

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Abstract

In view of the problem that circulating fluidized bed (CFB) boilers of various models and different performances used by many manufacturers in China cannot meet the requirements of increasing environmental protection standards, this manuscript mainly studied the universal accurate control technology of low nitrogen combustion in CFB. By investigating the common Selective Catalytic Reduction (SCR) design characteristics of domestic manufacturers and models of fluidized beds, a simple learning artificial intelligence control technology model based on System control theory was established to control nitrogen emissions more accurately by using monitors, sensors and collectors.. Through the analysis of specific industrial operation data, it is verified that the design idea of customized transformation of low nitrogen emission CFB boiler proposed in this paper is feasible and effective.

Keywords: Flexible Control, Circulating Fluidized Bed, Low Nitrogen Combustion, Optimize No_x Pollution Reduction, Artificial Intelligence, Commercialization Strategy.

Introduction

At present, China's NO_x emission standard is not allowed higher than 50mg/m^3. However, as the world-wide environmental protection requirements are further strengthened, the CFB technology also needs to be studied how to further reduce pollution emissions (He et al., 2021).

CFB boilers can be classified into two ultra-low NOx emission technologies: non-flue gas treatment (CFB) and conventional CFB secondary denitrification. Non-flue gas treatment reduces investment and operation costs, while conventional CFB uses flue gas treatment devices, but high operating costs (Li et al., 2021).

Compared with traditional coal-fired boilers, (CFB) boilers have the characteristics of large available fuel range, low combustion temperature, flexible load adjustment, and low pollution (Yang et al., 2021). Since it was introduced in China in the 1980s, CFB boilers have been popularized and applied at a high speed. The CFB boiler burns a mixed fuel that is pulverized into granular coal particles smaller than 12mm and mixed with calcium oxide particles with a diameter of 1mm, which can effectively solve the problem of inferior coal combustion. The combustion of the mixed fuel is mainly completed in the furnace, which is fed into the boiler through the hopper and burned into a fluidized state (Ke et al., 2021). The primary air required for combustion is sent from the bottom of the furnace, and the secondary air required for combustion is sent from the side wall of the furnace (Liu et al., 2020). The unburned solid materials are taken out of the furnace by the airflow and collected by the separator, and then sent back to the furnace for re-burning through the spill-back device. The separated flue gas is discharged through the convection flue, and the ash after burning is discharged from the furnace bottom ash and slag outlet (Saikia et al., 2021).

Based on the low nitrogen combustion theory and zoning optimization control method, the automatic control of CFB boiler combustion efficiency and separator, the optimization and transformation of the regulation of general components, so as to meet the requirements of reducing energy consumption and emission, and finally realize a more free, more accurate and simpler self-upgrading control technology (Kim et al., 2021)

The manuscript explores control theory and zonal optimization for automatic combustion efficiency and separators in CFBS. It aims to improve energy efficiency, reduce emissions, promote self-upgrading technology, and achieve efficient control technology. This contributes to sustainable development, energy conservation, and environmental significance in the industrial field.

Problem Statement

In view of the current situation that CFB boilers in China come from numerous domestic and foreign manufacturers, with many models and different performances, special customized low-nitrogen emission retrofits are required for each one. The precise control technology of low-nitrogen combustion needs to study the design common points of many manufacturers and models, and develops adjustable and controllable transformation schemes for general components. The control methods for ultra-low nitrogen oxide emissions of CFB boilers usually include pulverized coal input control, bed temperature control, primary and secondary air ratio control, secondary air input control, separator control, tail flue gas denigration, etc., From the moment the coal is transported to the furnace chamber, the pulverized coal can be zoning /grading combustion in the furnace through the pulverized coal input control. Once the mixed gas generated by combustion is separated by the control of the separator, the recovery part is returned to the furnace through the return material system, and the rest is discharged through the tail flue gas denitrification treatment. The common design that can be modified in this process includes two parts: the furnace chamber combustion system and the separator control system.

Limitations

Equipment heterogeneity: Although cross-manufacturer and cross-model low-nitrogen combustion control techniques are proposed in the study, there may still be large equipment heterogeneity among different CFB boilers. There are differences in the structure, materials and control system of boilers of different brands and models, which may limit the implementation of the adjustable and controllable transformation scheme of common components. More in-depth research is needed to address the challenges of device heterogeneity to technology promotion.

Changes in actual working conditions: the temperature partition and classification optimization control scheme in the furnace and other control schemes may be constantly changing in actual operation conditions, such as fuel types, load changes, etc. These changes may affect the stability and performance of the control system. In practical applications, it is necessary to consider how to adapt to these operating conditions to ensure that the proposed efficient control scheme can be maintained and reliable under various operating conditions.

These limitations need to be comprehensively considered and solved in further research and practical applications to ensure the actual effect of the proposed low nitriding firing control technology in different environments.

Literature Review

The mainstream CFB combustion technologies at home and abroad can be divided into the following categories:

(CFB) Temperature Control Combustion Technology

The NOx produced by coal combustion is mainly classified into thermal NOx and fuel NOx(Ke et al., 2018). Thermal NOx is produced by the oxidation reaction of nitrogen and oxygen in the air under high temperature conditions in the furnace, and fuel NOx is produced by organic nitrogen compounds in the fuel that are oxidized during the combustion process.

The amount of thermal NOx is mainly related to the furnace temperature, oxygen concentration and residence time in the high temperature zone, while the amount of fuel NOx is mainly associated with the nitrogen content of the fuel, the combustion temperature, and the excess air coefficient. When the maximum temperature (Tmax) < 1200℃, the proportion of fuel NOx is extremely high; when Tmax > 1600℃, the proportion of fuel NOx begins to decrease; when Tmax >1900℃, the proportion of fuel NOx is extremely low (Cahyadi et al., 2017). Generally, the temperature in the CFB boiler furnace is controlled at 850°C to 900°C, at this time, the NOx generated by coal combustion is mainly fuel NOx, and the amount of thermal NOx generated is tiny, usually less than 10% of the total NOx emissions. Meanwhile, the staged combustion technology adopted by the CFB boiler can also reduce the production of NOx. In different combustion zones in the furnace, combustion-supporting air is supplied in proportion to the amount of fuel supplied to form staged combustion, which can not only inhibit the formation of fuel NOx, but also reduce the generation of NOx staged combustion (Wei et al. 2021).

(CFB) Decoupling Low-nitrogen Combustion Technology

The decoupling low-nitrogen combustion technology divides the combustion process into two sections: partial pyrolysis and gasification under low-temperature reduction conditions and combustible burn-out under high-temperature oxidation conditions. Ultra-low emissions can be achieved through coke reduction and tar reburning and denitrification (Wei et al., 2021).

(CFB) Fluid State Reconstruction Combustion Technology

CFB fluid state reconstruction combustion technology is based on fluid state reconstruction technology, by adjusting boiler operating parameters such as the bed material particle size, circulating ash particle size, bed pressure drop, bed temperature, furnace outlet oxygen content, separator outlet ash particle size, primary air/secondary air ratio and fluidizing velocity to increase the circulation rate of the CFB materials, the bed effective fine particle inventory, and the separation efficiency of the cyclone separator, thereby increasing the particle concentration in the upper dilute phase zone of the furnace, this causes the reductive materials in the bottom dense phase zone, including unburned carbon and carbon monoxide, to move up, which enhances the reducing conditions in the furnace space and inhibits the formation of NOx (Zhang & Zeng, 2019). The characteristic of this method is that the average particle size of the bed material is greatly reduced compared with the CFB (Peng et al., 2017).

(CFB) High-temperature Post-combustion Technology

High-temperature post-combustion technology divides the combustion process of CFB into two sections: CFB furnace combustion and post-chamber combustion (Adnan et al., 2017). The CFB furnace combustion improves the reduction conditions in the furnace by controlling the parameters such as the primary and secondary air volume, so that the coal can be burned under weak reduction conditions after entering the furnace, thereby inhibiting the generation of NOx in the furnace. The incomplete combustion of coal will also produce a large amount of carbon monoxide, which entrains fine coke particles from the separator into the after-combustion chamber, and after-combustion air is introduced into the flue at the outlet of the separator (Zhu et al., 2021). The incomplete combustion of carbon monoxide and coke in the flue gas will be further burned in the post-combustion chamber to improve the combustion efficiency of pulverized coal and achieve ultra-low NOx emission in the CFB(Liu et al., 2021).

These Low-nitrogen combustion technologies have proven effective in controlling NOx emissions, but their practical applications require careful consideration of their advantages and disadvantages, as well as their long-term stability, cost-effectiveness, and impact on equipment maintenance, all of which need to be carefully balanced.

Research Questions

According to the content of literature review, the following research questions are summarized. These questions are consistent with the purpose of the study.

5.1 How do various operational factors within coal-fired power plant generation units impact the emission of NOx, and what patterns in their interplay can be identified through statistical analyses such as linear regression and multivariate analysis?

5.2 What are the quantifiable environmental consequences of implementing different optimization strategies on NOx emissions within power plant denitrification systems?

5.3 To what extent can machine learning models accurately forecast denitrification efficiency in power plant denitrification systems based on input NOx concentrations, and what implications does this have for operational cost-effectiveness?

5.4 In what ways do optimization strategies influence the correlation between predicted input NOx concentrations and actual emissions in power plant denitrification systems, and how can this insight be utilized for enhanced control, efficiency, and adherence to regulatory standards through IT-driven data analytics?

Research Objectives

In order to improve the control accuracy, it is essential to simulate the temperature distribution, gas flow distribution, nitrogen oxide distribution in the furnace chamber. This article mainly introduces with two parts: the temperature in the furnace and the temperature

of the separator (Xiao et al., 2021). The control of the temperature in the furnace is mainly achieved by zoning/grading flexible control to optimize the operating parameters of the CFB boiler to reduce the original emission of NOx, the main control methods include precise control of bed temperature, primary and secondary air ratio control and secondary air incidence angle control (Zhu et al., 2020). The control of the temperature of the separator is realized by controlling the key operating parameters such as the flue gas recirculation rate, the primary air rate, the upper and lower secondary air ratios, etc.
6.1 Investigate the Impact of Operational Factors on NOx Emissions
6.2 Assess the Environmental Consequences of Optimization Strategies
6.3 Evaluate Machine Learning Models for Denitrification Efficiency Forecasting
6.4 Examine Optimization Strategy Influence on Correlation and Control Measures

Research Methodology

Simulation Study: Architecture: Describe the specific type of neural network used (e.g., feedforward, convolutional, recurrent). Detail the number of layers, types of layers (hidden, dropout, normalization), and activation functions used in each layer.
Hyperparameters: Document the selection of learning rate, batch size, and number of epochs. Explain the rationale behind these choices based on preliminary experiments or literature.
Training Process: Describe the dataset splitting (training, validation, testing), including the proportions. Explain any data augmentation techniques used to enhance the model's ability to generalize.
Validation and Testing: Outline how the model's performance is evaluated, including the metrics used (e.g., accuracy, mean squared error, F1-score). Discuss cross-validation techniques if used.
Experimental Study: Implementation Details: Provide a detailed description of the Synchronous Perturbation Stochastic Approximation (SPSA) algorithm, including the calculation of the gradient estimate using simultaneous perturbation. Mention the specific choice of the gain sequences (a[k], c[k]) and their impact on convergence.
Algorithm Parameters: Justify the choice of parameters, such as the perturbation amplitude and the step size. Discuss how these parameters were tuned and their effect on the optimization process.
Convergence Criteria: Explain how you determine when the algorithm has converged to a solution. This might include setting a maximum number of iterations or a threshold for the change in the objective function.

Pilot Study

The flexible control system can improve coal combustion efficiency to reduce NOx emissions and protect the environment. Table 1 is a comparison list of NOx emissions after using of zoning/grading flexible control:

Table 1
NO_X Emission List After Using Multi-Stage Control Method

Implementation effect	Combustion efficiency	Coal consumption	Load running time	NO_x reduction
1 zone	+0.5%	-539t	6900h～7000h	4.1879t
2 zones	+0.8%	-860t	6900h～7000h	6.3206t
3 zones	+1.0%	-1075t	6900h～7000h	7.9557t
4 zones	+1.1%	-1170t	6900h～7000h	8.6526t

First at all, data in Table 1 is used to make a rough calculation of the nitrogen saving amount of a certain series of CFB, taking the “Zhongzheng” brand DHX(Product model) series of CFB steam boiler as an example. The capacity of this type of boiler is 35-100/t/h, equivalent to the specifications of 50-140/mw, roughly the coal consumption is about 15.4g/kwh, and the annual NOx emissions is about several thousand tons.

If the control efficiency is increased by 0.5%, the coal consumption can be reduced by 0.77g/kwh. Under the current power consumption situation, based on a plant's full-load operation time of 6,900-7,000 hours per year, assuming a minimum of 5,000 hours, the coal consumption can be reduced at least 0.77*140,000*5,000=539,000,000g, which is 539 tons.

According to the pollution equivalent calculation formula in the "Management Measures for the Collection of Pollutant Discharge Fees", starting from April 1, 2014, each ton of coal will emit 0.0074 tons of NOx. If the combustion efficiency is increased by 5%, then the pollution equivalent of NOx emissions will be reduced by 539t*0.0074/0.95=4.2t, and the total NOx emission reduction in 7 years is 29.4 tons/unit.

These data in Table 2 are the most conservative estimates. Prior to signing a contract, the implementer generally needs to conduct an on-site inspection of a plant, and only after checking the historical data and the adjustment capabilities of various types of control equipment, a more accurate performance improvement guarantee data will be given, especially NOx emissions, is generally believed to be reduced by more than 12% on average.

Example: Jiangxi Ganfeng Lithium Co. Ltd., a leading enterprise in Lithium industry in China, is specialized in R&D, production and management of Lithium and deep processing Lithium compound products. In order to improve production efficiency, Ganfeng Lithium purchased a set of“Zhongzheng” brand DHX series 35 tons energy-saving CFB in 2017. In 2018, parameters of the control scheme of this series of products were debugged and experimental data were obtained, as shown in Figure 1 below.

In 2019, Ningdu County Ganfeng Lithium Co., Ltd., a subsidiary of Ganfeng Lithium, plans to invest in a 17,500 ton battery-grade lithium carbonate production line project. Purchase again "Zhongzheng " brand DHX series 50 tons energy-saving CFB. In addition, the above four level optimization control scheme is implemented in this project. Make its load adjustment range is large, load adjustment is fast. Compared with the “Zhongzheng” brand DHX series 35 tons energy-saving CFB purchased by the brand in 2017, in the whole year of 2020, the data of relevant environmental monitoring departments under the same use conditions and duration shows that the NOX emission of the latter is reduced by 10.08% compared with that the modification of the flexible control system, as shown in figure 2 below.


Figure 1: The project of 2017


Figure 2: The project of 2019

Through the above analysis, it can be concluded that the implementation of hierarchical optimization control system not only effectively reduces the emission of nitrogen oxides, but also reduces the energy consumption and improves the operation level of employees; It has also achieved the most direct economic benefits, so as to save energy, reduce consumption and reduce pollution.

Data Analysis Plan

The temperature control of the separator is to control the combustion time of the mixture through the after-combustion characteristics of the mixture. Once the CFB runs at full load, the temperature of the mixed gas entering the separator will easily rise to the reaction window temperature. At this time, the mixed gas should be fully burned in the furnace to shorten the combustion time of the mixed gas in the separator to reduce the temperature of the separator to prevent the temperature of the separator from exceeding the upper limit of the reaction window temperature; when the load is declined, the fuel input into the furnace is reduced, and then the mixed gas of the cycle combustion is reduced, so that the temperature of the separator is reduced, and the combustion time of the mixed gas in the furnace should be reduced at this time to enhance the combustion time in the separator to increase the temperature of the separator, and prevent the temperature of the separator from falling below the lower limit of the reaction window temperature. To control the combustion time of the mixed gas in the furnace, the height of the dense phase zone in the furnace can be adjusted, and the height of the dense phase zone in the furnace can be adjusted by changing the ratio of the upper and lower secondary air and changing the height of the incidence of the secondary air.

The lower the height of the dense phase zone, the longer the combustion time of the incompletely combusted gas in the mixed gas in the furnace, and the lower the outlet temperature of the separator; the higher the height of the dense phase zone, the shorter the combustion time of the incompletely combusted gas in the mixed gas in the furnace, the higher the outlet temperature of the separator. Meanwhile, under the condition of constant total air volume, a higher primary air ratio will provide more oxygen for early combustion in the dense phase zone, accelerate the combustion of the mixed gas in the furnace, increase the burn-out rate in the separator, and lower the outlet temperature of the separator.

Specifically, the temperature sensor is mainly used to collect the inlet and outlet temperatures of the separator, calculate the temperature rise rate of the separator, compare the collected outlet temperature of the separator with the upper and lower limits of the reaction window temperature, and compare the temperature rise rate of the separator calculated with the positive rate of allowable temperature rise of the separator.

When the outlet temperature of the separator is greater than the upper limit of the reaction temperature or the temperature rise rate of the separator exceeds the allowable temperature rise rate of the separator, the control system will send an alarm signal for the excessive temperature rise of the separator or a warning signal for the excessive temperature rise of the separator, and the upper secondary air door shrinks or rays move down, lower secondary air door opens or ray moves down, control the outlet temperature of the separator to be within the temperature range of the reaction window. When it is collected that the outlet temperature of the separator is lower than the lower limit of the reaction window temperature or the temperature rise rate of the separator is less than the negative rate of allowable temperature rise of the separator, the control system will send a separator temperature ultra-low alarm or a separator excessive temperature drop warning signal, and the upper secondary air door opens or ray moves up, and the lower secondary air door shrinks or ray moves up to control the outlet temperature of the separator within the temperature range of the reaction window. When the outlet temperature of the separator is within the temperature range of the reaction window and the temperature rise rate of the separator does not exceed the allowable rate of the separator, the control system maintains the current state and fines tuning the upper and lower secondary air doors to control the temperature rise rate of the separator within the allowable temperature rise rate range of the reaction window temperature. The temperature control flow chart of the separator is shown in Figure 3 below:

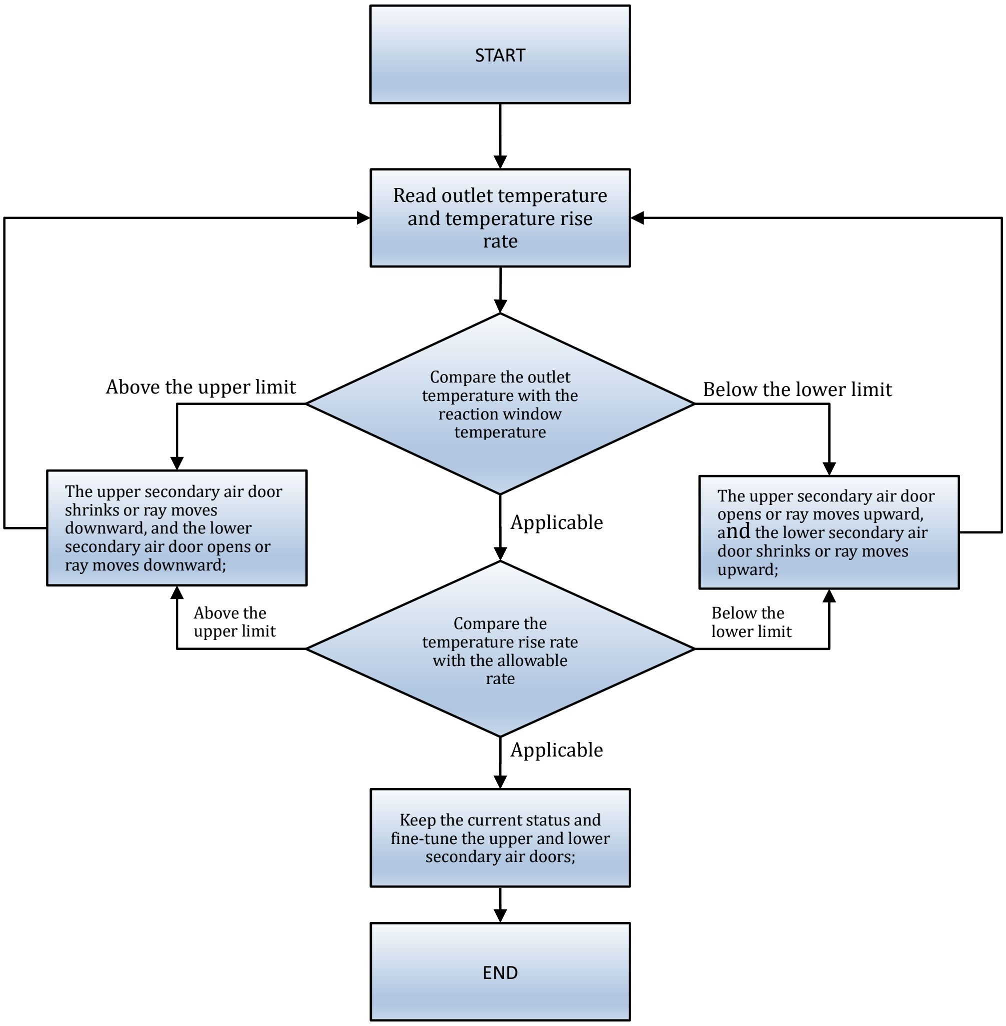

Figure 3: Schematic diagram of the temperature control flow of the separator

In order to adapt the differences in the control process, control parameters and control logic of many manufacturers and models, CFB low-nitrogen combustion precision control system is necessary to perform simple artificial intelligence training based on simplified input fully supervised convolutional neural networks. To put it simply, it is to use monitors, sensors or collectors to collect the daily manual control process of the management personnel on the circulating fluidized bed, extract the management control logic under various working conditions through the convolutional neural network, and finally form artificial intelligence control through continuous learning system. The flow chart of control logic is shown in Figure 4 below:

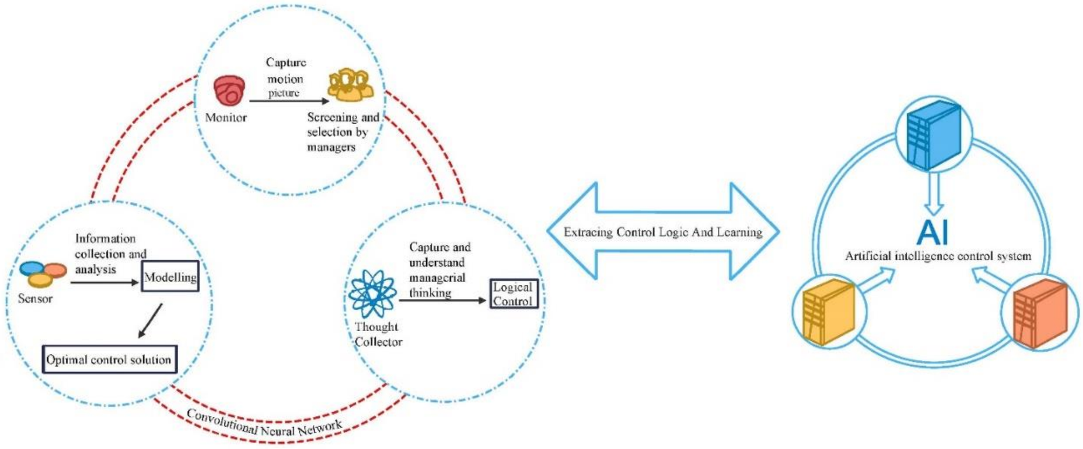

Figure 4: Control logic diagram

The way of using the monitor is mainly performed by capturing the designated action or natural action of the manager. Designated action capture means that the manager does not directly operate the management system, but the system describes the natural operation or simulated operation under the supervision and teaching system, and the manager selects the control plan for this kind of operation, such as zoning in line, raising hands command and other ways, a variety of preset control schemes are handed over to managers for selection, and designated actions are made according to the choices, and the supervising teaching system recognizes and records the designated actions through the monitor; natural action capture refers to managers operate directly on the management system, where the operation includes both computer input device operation and electric control panel operation. The computer input device operation is directly recorded by the system, and the electric control panel operation is recognized and recorded by the monitor, and then through the current operating conditions and subsequent operating conditions, matching with the operating records and learning. The difference between the two methods is that natural action capture does not affect the normal operation but the learning time is longer. The designated action capture learning process basically does not participate in the normal operation, but the data accumulation is fast and the learning time is short. Both methods have their own advantages.
The method of using sensors is mainly to collect and analyze the whole process parameters and control instructions of the CFB operation process, establish the operation model of each main part of the CFB, and establish the steady-state operation control logic according to the operation model, and simulate the control result, and perform actual control according to the optimal result plan. The main problem with this method is that the establishment of the system is actually a process of repeated trial and error. There are a large number of invalid variables or invalid operations, causes the system to process a large amount of invalid data, which requires higher computing power and more calculation time, a certain control delay may be occurred; the main advantage is that it may find a better control scheme or control method that has not been discovered so far, and optimal solution of the final actual control effect can be achieved through a long period of iterative learning.
The use of collectors mainly refers to the use of brain wave collectors, VR (Virtual Reality)or AR(Augmented Reality) collectors and other mind collectors, which directly compile the management staff's operational consciousness or thoughts into control logic. Compared with other methods, the mind collector is still under research, and there is no device that can be used directly. Judging from the current research progress at domestic and overseas, this

method will have the conditions for implementation in the next 3 to 5 years. Through the mind collector, it is possible to collect and understand the purpose of the operation and the predicted result of the manager without affecting the normal work. Compared with the use of a monitor to capture, the error rate is greatly reduced, and the result obtained is more direct and at the same time, it can check the effectiveness of the operation by comparing the actual operation result with the predicted result, and directly screen out the collected error results. Compared with the way the sensor collects the data, the learning time is greatly shortened and it can also directly deal with the operating difference of technological updating/renovation of the equipment in the future.

Data Analysis

There are many factors that affect the temperature in the fluidized bed furnace, including coal quality, coal feed volume, air volume, primary and secondary air ratio, bottom slag discharge volume, bed height and load changes, among which coal feed volume, and primary and secondary air volume is the main adjustable factor. Changes in coal feed volume, primary and secondary air volume, and furnace temperature in the constant load test can be done by observing and recording, and the response curve and real-time sampling data can also be recorded. The coal feed volume and the primary and secondary air volumes are selected as input variables. Taking into account the delay effect of each input volume on the temperature in the furnace, the time series order of the coal feed volume takes STAGE-3, and a 50s delay is added, and the primary air volume takes STAGE-2, the historical moment in the furnace takes STAGE-1, then the input and output equation of the furnace combustion temperature model can be expressed as:

$$y0(k)=f[y(k-1),u1,u2] \quad (1)$$
$$u1=f[u1(k-6),u1(k-7),u1(k-8)] \quad (2)$$
$$u2=f[u2(k-1),u2(k-2)] \quad (3)$$

Wherein: Y is the average furnace temperature output as a controlled object, U1 is the coal feed quantity as the system input, and U2 is input as another air volume applied to the system. K is the set value of combustion temperature at a certain time in the furnace.

In order to achieve more precise combustion control, the furnace is planned to be zoned, and each different zone is controlled in stages. At this time, the input and output equations of the combustion temperature model in the furnace can be expressed as:

$$y(k)=f[y1(k),y2(k) \ldots\ldots yn(k)]T \quad (4)$$
$$yn(k)=f[yn(k-1),un1,un2] \quad (5)$$
$$un1=f[un1(k-6),un1(k-7),un1(k-8)] \quad (6)$$
$$un2=f[un2(k-1),un2(k-2)] \quad (7)$$

Wherein: Y(k) is the average furnace temperature output as a controlled object, yn is the average temperature of zone and stage, un1 is the coal feed volume, un2 is input as another air volume applied to the system, and K is the set value of combustion temperature at a certain time in the furnace. The simulation comparison results after the 4-zoning/grading control in the furnace are shown in Figure 5-9 and Table 2.

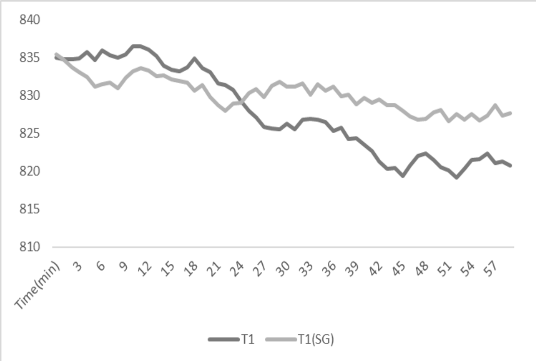

Figure 5 Average temperature of zone-1

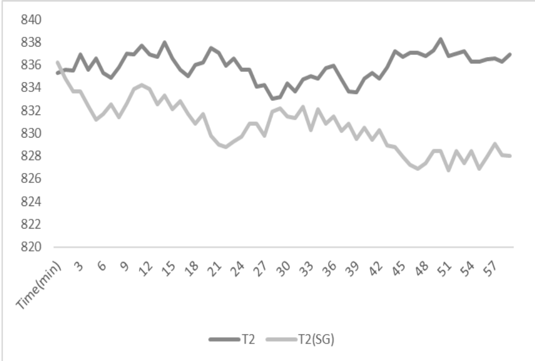

Figure 6 Average temperature of zone-2

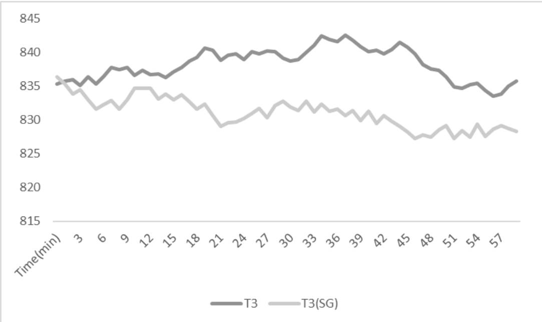

Figure 7 Average temperature of zone-3

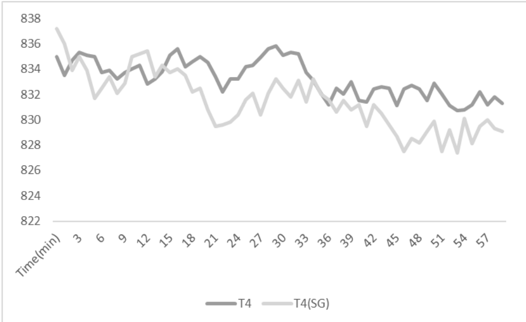

Figure 8 Average temperature of zone-4

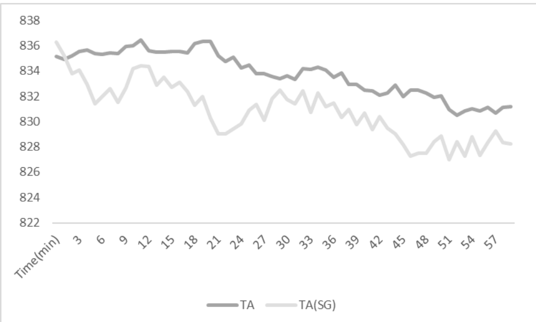

Figure 9 Average temperature in the furnace

Table 2
Comparison Table of the Two Control Methods

Control method	**Integral control**					**Zone and stage control(SG)**				
Zone	T1	T2	T3	T4	TA	T1(SG)	T2(SG)	T3(SG)	T4(SG)	TA(SG)
Average temperature	827.77	835.9	838.16	833.26	833.77	830.16	830.57	831.02	831.49	830.81
Difference	-6.00	2.13	4.39	-0.51		-0.65	-0.24	0.21	0.68	
Variance	36.0000	4.5369	19.2721	0.2601	60.0691	0.4225	0.0576	0.0441	0.4624	0.9866

Finding and Conclusion

Aiming at the current situation of CFB boiler industry in China, this paper studies the cross manufacturer and cross model accurate control technology of low nitrogen combustion. Through the research on the design commonalities of various manufacturers and models, the adjustable and controllable transformation scheme of general components is proposed, including the temperature zoning and hierarchical optimization control scheme in the furnace and the temperature control scheme of the separator. By using monitors, sensors or collectors to collect the daily control process information of managers, an artificial intelligence control system is established, and an artificial intelligence control technology based on simple learning is proposed. The research in this paper shows that with the development of computer technology, especially artificial intelligence technology in the future, the accurate control technology of low nitrogen combustion of CFB boiler will usher in a wave of leapfrog development.

Developing a Precise Control Technology for Low Nitrogen Combustion in Circulating Fluidized Bed not only enhances environmental compliance but also aligns with a strategic commitment to sustainable and efficient energy solutions, reinforcing competitiveness in the dynamic landscape of industrial practices.

Recommendation

The article suggests several recommendations for promoting the development and promotion of low nitrogen combustion control technology in the CFB boiler industry. These include developing a unified technical standard, conducting field verification and case promotion, implementing training programs for operations personnel and managers, establishing a long-term monitoring and maintenance plan, promoting industrial ecological chain cooperation, and seeking policy support from the government and related industries. These recommendations aim to ensure the practical application of research results and promote sustainable development of the CFB boiler industry. By implementing these recommendations, the industry can achieve a unified level of standardization and unified industry development.

Acknowledgement

The research team is grateful to the power company managers who generously shared their rich insights and experiences and provided valuable support for this study. The candid views of respondents shed light on the complex landscape surrounding environmental pollution by nitrogen oxides in the context of expected changes in electricity supply. The valuable contributions of these industry professionals not only deepen our understanding of the issues, but are also expected to be a valuable reference for policy makers and business managers in the decision-making process. The pool of knowledge gathered in this collaboration plays a vital role in addressing the complex challenges and opportunities in the global energy and environment sector, affecting every aspect of production and daily life.

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