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Design and Application of Low-NOx Burners in Rotary Kilns

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Abstract. In an era of heightened environmental consciousness and stringent pollution controls, the reduction of air pollution, particularly nitrogen oxides (NO_x), has emerged as a universal goal. In response to the increasingly rigorous NO_x emission standards for industrial furnaces, our innovative research has yielded a groundbreaking solution. By engineering a novel five-channel vortex low NO_x burner and implementing it in a company's lime rotary kiln, we have achieved a remarkable reduction in NO_x emissions. The average NO_x content in the kiln's tail gas, previously at 450mg/m^3 and in violation of industry standards, has now been successfully decreased by over 30%. This cutting-edge burner technology not only ensures compliance with environmental regulations but also reaches a record-low NO_x emission concentration of 135.56 mg/m^3 during operation, effectively demonstrating our commitment to and success in controlling NO_x emissions. This breakthrough marks a significant contribution to the field of industrial environmental protection and showcases our leadership in developing sustainable industrial practices.

Keywords: Low NOx Burner; Air Pollution; Rotary Kilns

1. Introduction

Lime rotary kiln is the first choice for industrial production of quicklime. However, the burner used in rotary kiln not only provides energy, but also produces a large amount of NO_x [1]. A large amount of NO_x emissions have a serious impact on the environment and human health [2], so it is urgent to carry out research on NO_x reduction in lime rotary kiln.

The NO_x emission is caused by fuel-based type, fast type, thermal type and backfiring type [3]. For the lime rotary kiln, the formation of NO_x in the furnace is mainly composed of thermal NO_x and rapid NOx produced by local high temperature caused by uneven mixing of fuel and air. Many scholars pay attention to the development of new low-NO_x burners [4,5], optimize the combustion organization process and improve the combustion efficiency, in order to reduce NO_x emissions from the source. Therefore, a new type of low-NO_x burner is designed according to the calcination process and operation parameters of a lime rotary kiln in a company, which provides a valuable reference for engineering design and application.

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2. Production status of lime rotary kiln

The actual capacity of a lime rotary kiln in a company is 800 t/day. It uses pulverized coal as fuel and uses four-channel swirl burner. The NO_x content in tail gas is about 450 mg/m^3, which exceeds the industrial emission standard and does not meet the environmental protection requirements, and even directly threatens the production. If the denitration system is put into use, the annual operating cost will be increased by about 5.5 million yuan without considering the project investment, and the cost will be increased by at least 20 yuan/ton of lime, which will significantly increase the investment cost. Therefore, the combustion system of rotary kiln in this company was reformed to reduce NOx content in tail gas. The rotary kiln production site is shown in Figure 1.

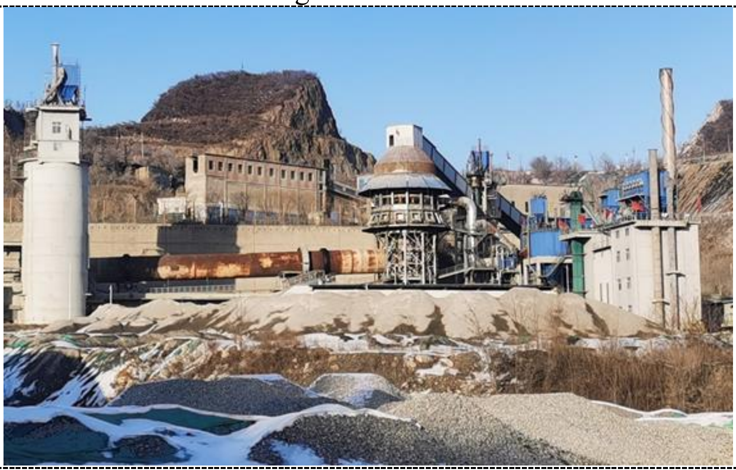

Figure 1. Production site diagram of rotary kiln.

3. Design of Low-NO_x Burner

In response to the company's lime rotary kiln equipment specifications, calcination process conditions, and NOx emission criteria, a novel five-channel vortex flow low-NOx burner has been engineered. The burner's architecture comprises an external axial air duct, a coal air duct, a swirl air duct, a vortex air duct, a central air duct, a support tube, a central sleeve, and air inlet ducts, as depicted in Figures 2 and 3.

The nozzle of the external axial flow duct is designed with a semi-circular aperture featuring a specified inclined taper, which diminishes wind resistance and enhances jet intensity. The external axial flow air is intermittently sprayed through semi-conical holes, and the high-speed air is ejected in a rotating manner, thereby thoroughly entraining high-temperature secondary air and effectively diffusing pulverized coal. The outlet area of the external axial flow duct is capable of seamless adjustment, allowing for the fine-tuning of the outlet wind speed and flow rate of the external axial flow air.

The pulverized coal air duct is positioned between the external axial flow air duct, the pulverized coal channel, and the swirl flow air duct. Under the influence of the external axial flow wind and the cyclone wind, the pulverized coal diffuses rapidly, promoting quick ignition. By managing the direction and distribution of the pulverized coal within the kiln under the combined action of external axial flow and swirl flow, the flame shape and temperature distribution can be effectively modulated.

The swirling air passage is situated within the coal powder channel, and it ejects multiple high-speed swirling air streams through a series of tapered semicircular spiral grooved swirlers, generating a swirling effect. This ensures that the coal powder diffuses rapidly and evenly after exiting the burner, reducing the coal powder concentration and enhancing the contact time and area between fuel and air. This, in turn, facilitates faster fuel combustion and improves fuel burn efficiency. The outlet area of the swirl duct can be continuously adjusted, thereby allowing for the alteration of the external swirl wind's outlet wind speed.

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The vortex air channel is positioned inside the swirl air channel. It features multiple semicircular spiral groove swirlers with varying spiral angles to spray out multiple high-speed vortex air streams. The swirler of the vortex air channel can modify the angle of the vortex air by adjusting axial displacement, thus regulating the flame shape, effectively forming internal backflow, fully entraining secondary air, and collaborating with the swirl air to achieve a more stable combustion flame.

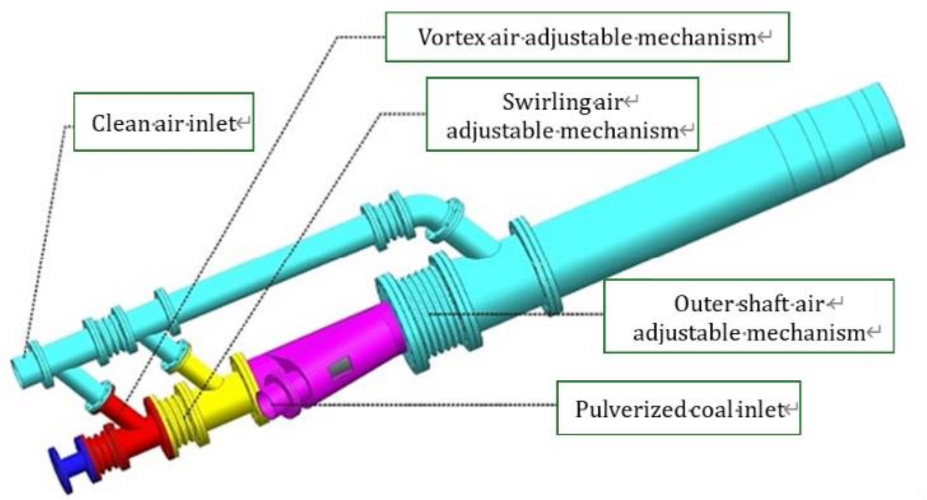

Figure 2. Structure diagram of five-channel vortex flow low-NO_x burner.

Figure 3. Head diagram of five-channel vortex flow low-NO_x burner.

The main technical advantages of the five-channel vortex flow low-NO_x burner are as follows:

① Higher primary wind speed and lower primary air volume.

② High thrust and speed difference are adopted, and fuel and wind are fully mixed.

③ High flame intensity, great rigidity and strong stability.

④ The thickness and length of flame can be adjusted to form an ideal thermal power system.

⑤ Helical jet ensures full mixing of air and pulverized coal and full entrainment of high-temperature secondary air.

4. Performance analysis of low-NO_x burner

Based on the above design of low-NO_x burner in rotary kiln, a new burner was manufactured and installed in this study, and put into use. In the actual operation, the low-NO_x burner has the advantages of convenient on-line adjustment of flame length, strong process adaptability and stable combustion flame, etc. The air pressure of the external axis air duct, swirl air duct and vortex air duct of the burner

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are all controlled within 35~40 kPa, the kiln condition is well controlled, and the pulverized coal consumption is reduced by 0.2 t/h.

The comparison of NO_x monitoring data at the end of lime rotary kiln before and after using low-NO_x burner is shown in Table 1.

The calculation formula of NO_x emission reduction rate is:

$$R = \frac{E_{before} - E_{after}}{E_{before}} \times 100\%.$$

Table 1. Comparison of monitoring data of NO_x in rotary kiln.

Testing items	Traditional burner [mg/m^3]	New burner [mg/m^3]
Maximum NO_x	387.10	284.01
Minimum value of NO_x	276.54	192.16
Average value of NO_x	288.07	200.66

where R is the emission reduction rate of NO_x, [%]; E_{before} is the NOx emission concentration of traditional burner, [mg/m^3]; E_{after} is the NO_x emission concentration of the new burner, [mg/m^3].

In addition, the average concentration of NO_x in one week of traditional burner and new burner is selected to analyze the average emission reduction rate, and the calculation results are shown in Figure 4. During the seven days, the average emission reduction rate of NO_x was as low as 30.24% and as high as 46.13%, and the emission reduction effect was considerable.

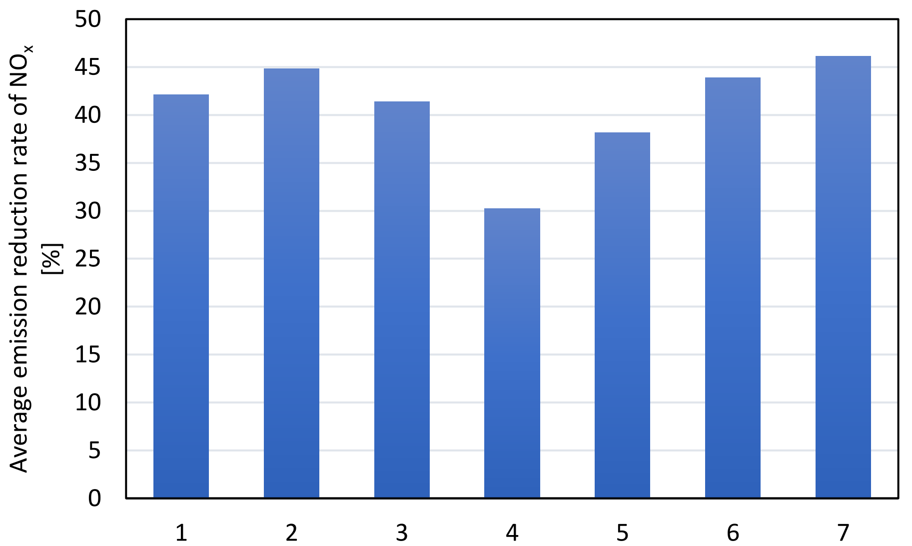

Figure 4. Seven-day statistical chart of average emission reduction rate of NO_x.

In addition, the daily average concentration of NO_x in lime rotary kiln with new burner is analyzed. As can be seen from Figure 5, the average emission concentration of NO_x after adopting the new burner does not exceed 250 mg/m^3 every day.

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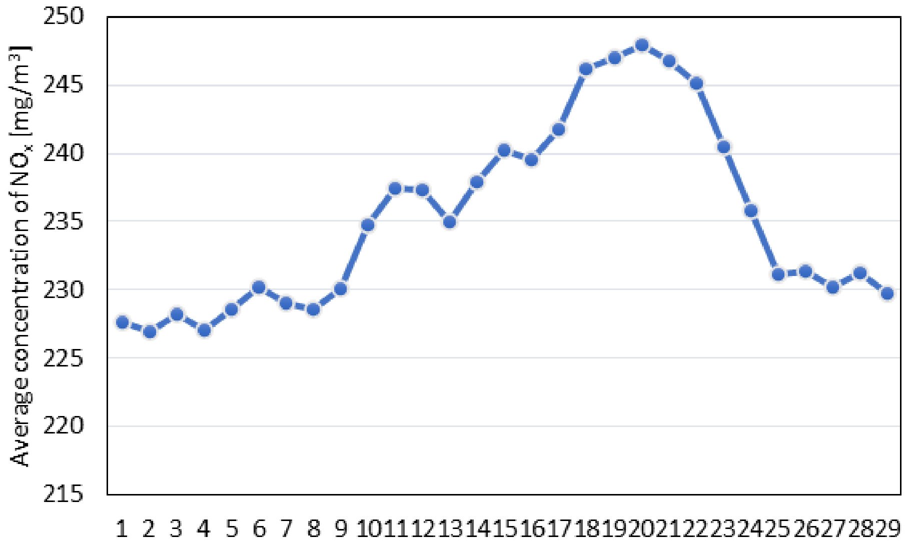

Figure 5. Daily comparison chart of NO_x at the end of rotary kiln.

The empirical data and the extensive production practice spanning several months have categorically validated the efficacy of the low nitrogen burner in mitigating NO_x emissions. The results are nothing short of remarkable, with the average NO_x emission concentration at the kiln tail demonstrating a substantial reduction exceeding 30%. Moreover, during operational cycles, the burner has achieved an impressive low of 135.56 mg/m^3 for NO_x concentration, signifying a significant environmental milestone.

These findings underscore the resounding success of the low-NO_x burner's application within an 800-ton lime rotary kiln production line. The burner has not only met but exceeded expectations in terms of NO_x emission reduction, delivering satisfactory and quantifiable outcomes. The deployment of this innovative technology in the lime production industry represents a crucial step forward in the quest for more sustainable and environmentally responsible industrial practices.

5. Conclusion

In this study, we meticulously designed a novel five-channel vortex low-NO_x burner tailored to the equipment parameters, calcination process conditions, and NO_x emission requirements of lime rotary kilns. The burner, featuring an intricate structure with components such as an external axial flow air duct, coal air duct, vortex air ducts, central air duct, support pipe, central sleeve, and various air inlet pipes, ensures optimal fuel mixing and flame stability.

The application of this innovative low-NO_x burner in lime rotary kilns has led to a significant reduction in NO_x emissions, with the average concentration at the kiln tail decreasing by at least 30%, comfortably meeting and surpassing the industrial emission standard of 300 mg/m^3. The operational data confirm the burner's effectiveness, with the minimum NO_x emission concentration reaching an impressive 135.56 mg/m^3, thus demonstrating effective NO_x emission control.

As environmental protection garners increasing attention, the prospects for the widespread adoption of low-NO_x combustion technology in lime rotary kiln production are promising. However, it is important to acknowledge the limitations of the current study and to identify areas for future research:

The current study was focused on a specific type of lime rotary kiln and may not be directly applicable to all kiln designs or firing conditions. Further research should explore the burner's effectiveness across a variety of kiln types and operating scenarios.

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While the burner has been successful in reducing NO_x emissions, the impact of these changes on the quality and production rate of lime was not fully investigated. Future studies should assess the burner's influence on product quality and overall kiln efficiency.

The long-term durability and maintenance requirements of the new burner design have not been evaluated. Additional research is needed to understand the lifespan and cost implications of the burner in industrial settings.

The economic and environmental impact of the burner's implementation on a larger scale should be assessed to guide industrial stakeholders in making informed decisions about adopting this technology.

By addressing these limitations and pursuing the identified directions for further research, we can enhance the burner's design, optimize its performance, and contribute to the sustainable development of the lime production industry.

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