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Application of an integrated device for ultra-low temperature desulfurization and denitration in large rotary kiln

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Abstract. To tackle the problem of excessive nitrogen oxide emissions during the denitration process of the lime rotary kiln at Beitai Iron Mine, it was proposed to integrate ultra-low temperature SCR denitration catalysts and a moving-burden bed reactor into a radial combined desulfurization and denitration device to achieve ultra-low temperature denitration in a low-sulfur state. The self-built integrated device features two desulphurization beds and one denitration bed, through which the flue gas passes successively in a radial flow manner. Industrial test results indicate that the denitration efficiency reached an average of 96.07% at temperatures ranging from 70 to 130°C during a 14-day test period, indicating a good denitration effect. The ultra-low temperature SCR denitration device has been put into use, effectively reducing nitrogen oxide emissions and air pollution, while also promoting the optimization and upgrading of the energy structure. The research results can provide a reference for the environmental management of mining and processing enterprises.

Keywords: ultra-low temperature; SCR denitration; nitrogen oxide emission; rotary kiln

1. Introduction

Lime rotary kilns are crucial equipment for processing raw limestone minerals. The flue gas produced during lime production contains a large amount of high concentration of NO_x, making it a significant source of industrial pollution. Thus, controlling the emission of NO_x in rotary kilns has become a pressing issue. Selective catalytic reduction (SCR) technology is widely used in metallurgy, power, cement and other fields, due to its high efficiency, strong adaptability, and technical maturity[1]. However, conventional SCR techniques typically require a flue gas temperature of over 300°C for the catalysts to be active and selective enough to carry out denitration reaction[2]. Furthermore, this process results in increased energy consumption and production costs, and may also lead to equipment corrosion and catalyst poisoning[3]. The ultra-low temperature SCR technology presents a potential solution to above issues. This technology employs catalysts to facilitate the reaction of reducing agents, such as ammonia or urea, with NO_x, producing the harmless N_2 and H_2O at temperature typically below 180°C[4]. Thus, the low-temperature flue gas emitted by lime rotary kilns can be treated directly without requiring additional external heat.

Here, we take the 800-ton large lime rotary kiln of Beitai Iron Mine as an example to describe an integrated SCR industrializing device, which combines a moving-burden bed reactor with ultra-low temperature SCR catalysts for desulfurization and denitration of flue gas at ultra-low temperatures. The effect of synergistic desulfurization and denitration was evaluated based on the testing condition of flue gas in actual engineering. The research results can provide a reference for the environmental management of mining and processing enterprises.

2. SCR denitration catalyst

CDM-2CXTX catalysts (Figure 1), developed by the Institute of Process Engineering of the Chinese Academy of Sciences, were selected for ultra-low temperature SCR denitration of rotary kilns. These catalysts can be adequately activated at 110°C, with an operating temperature range of 70°C to 180°C. The catalysts are non-toxic and do not generate hazardous waste. The deactivated catalysts can be regenerated through the washing-calcination technique. Besides, the catalysts are only suitable for use in flue gas with SO_2 concentrations lower than 30 mg/Nm^3. This is because the sulfur in flue gas is easy to form ammonium sulfate with ammonia reducing agent at low temperatures, which hinders the micropores of the catalysts and makes the catalysts poisoned and deactivated[5].

Figure 1 CDM-2CXTX catalysts

3. Moving-burden bed reactor

The moving-burden bed reactor possesses good design flexibility and adaptability, and allows for precise control of reaction parameters, making it suitable for most industrial flue gas governance. To prevent high concentrations of acidic SO_2 affecting catalyst activity, two desulfurization bed layers were included before the denitration bed layer. The desulfurization bed layers have a total filling volume of approximately 1.5 m^3, and activated calcium oxide solid granules are used as desulphurization agent. During actual testing, the SO_2 concentration at outlet consistently remained below 10 mg/Nm^3. After removing dust and sulfur, the flue gas passes through the denitration bed for NO_x removal. The denitration bed layer is filled with approximately 0.75 m^3 of catalysts. Compared to fixed bed or fluidized bed reactors, the moving bed reactor can achieve the integrated removal of multiple target pollutants, and allow for flexible arrangement of reactor position and controllable design of shape and dimensions according to the denitration site. The reactor can automatically load and unload materials through the top feeding port and tail unloading port, and the catalysts can be replaced without interrupting continuous operation of the device.

4. Process and system configuration

There are two main technological routes for ultra-low temperature SCR technology to remove NO_x from industrial kiln flue gases, the traditional and novel process routes. The traditional process route involves several stages, including dust removal using bag filters, heat exchange, heating by the heater, ultra-low temperature SCR denitration, induced fan, and direct discharge through the chimney. The novel process route proceeds through dust removal, ultra-low temperature SCR denitration, induced fan, and direct discharge chimney in sequence. A comparison reveals that the traditional process route is longer, has higher flue gas resistance, and covers a larger area. Additionally, it requires heaters and exchangers to heat the flue gas, resulting in increased equipment investment, energy consumption, and operating expenses. So we chose the novel process route (Figure 2) that is relatively simple, has low flue gas resistance, requires no additional heating equipment, allows for online loading and unloading of catalysts, does not affect the continuous operation of the overall unit, and has low investment and operating costs.

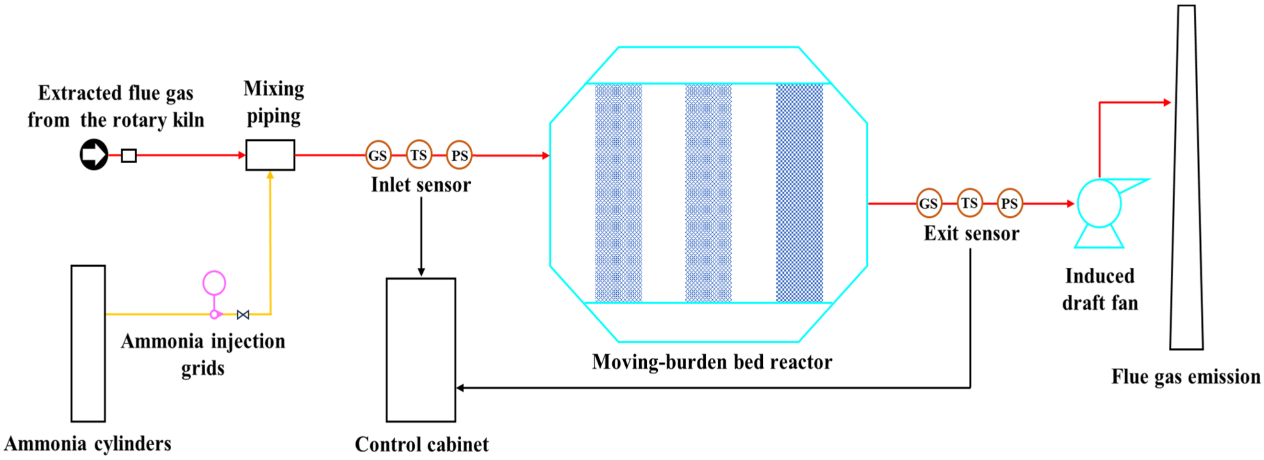

Figure 2 Structure of moving-burden bed reactor

The ultra-low temperature SCR denitration device consists of reductant system, flue system, moving bed reaction system, variable frequency fan, and control system. Reductant system consists of liquid ammonia cylinders, ammonia injection grids and process piping, which are primarily used for the storage, transport and injection of reductant. Flue system comprises inlet and outlet flues, as well as flue supports for transporting gas. Moving bed reaction system contains the reactor body, desulfurization agents and ultra-low temperature SCR catalysts, which provides space for denitration reaction. Variable frequency fan is primarily used to regulate air volume and pressure, ensuring efficient and stable operation of the system. Control system, comprising a PLC-integrated distribution cabinet, field thermometers, and float flow meters, is responsible for operating and monitoring data for the entire system configuration.

The induced draft fan is utilized to extract the kiln flue gas, which has been treated by the bag filter, along the new bypass flue. The extracted gas is evenly mixed with the reductant sprayed into the ammonia spraying grill. The mixed flue gas undergoes desulfurization and denitration reactions in the moving bed reactor. The flue gas is initially treated by the desulfurization bed to meet the acidic gas concentration requirements of the denitration inlet. Subsequently, it enters the denitration bed, where the NO_x in the flue gas is reduced. The extractor fan can adjust the flue gas flow rate to enable the catalyst testing under different airspeed conditions. Monitoring points for temperature, pressure, flow, and flue gas pollutant concentration detection ports are located at the inlet and outlet of the reactor to facilitate the acquisition of operational data from the system. The denitrified flue gas is then returned to the original flue system and discharged through the chimney.

5. Application of ultra-low temperature SCR device in large rotary kiln

The denitration efficiency of an ultra-low temperature SCR device was investigated during a 14-day engineering application test on the lime rotary kiln at Beitai Iron Mine. The test was conducted at different temperature intervals with flue gas flow rate of 2000 Nm^3/h, ammonia flow rate of 0.35 Nm^3/h, and pumping fan frequency of 15 Hz.

The denitration efficiency was at its lowest (92.52%) when the reaction temperature of flue gas ranged between 70~80°C (Figure 3). The denitration efficiency increases gradually as the temperature of the flue gas increases. The device achieved its highest denitration efficiency (98.74%) at 120~130°C. This temperature range aligns with the applicable activity temperature range of the catalyst. The denitration efficiency of the device during operation was 96.07%, surpassing other denitration devices reported in the literature[6]. Additionally, the average NO_x concentration in the flue gas at the reactor outlet was 7.8 mg/Nm^3, well below the limit value of 100 mg/Nm^3 specified in the ultra-low emission standard for the steel industry. This device has the potential for industrial application as it can efficiently achieve flue gas denitration in lime rotary kilns at ultra-low temperatures (below 130°C) while maintaining a low NO_x concentration at the outlet.

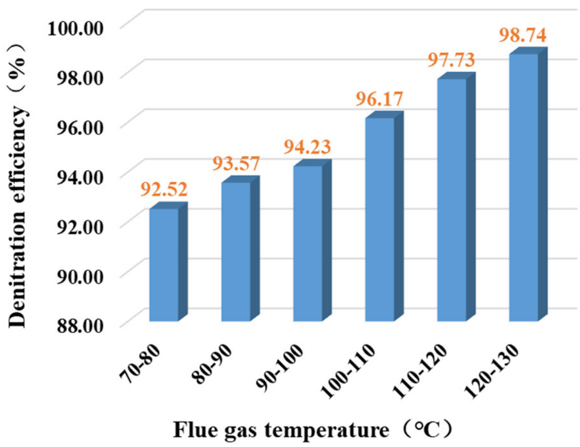

Figure 3 Denitration efficiency of the device at different temperature ranges

6. Summary

The ultra-low temperature SCR device shows good industrial effect in denitrifying flue gas from large lime rotary kilns, and maintains an average NO_x conversion rate of 96.07% at ultra-low temperatures ranging from 70 to 180°C. Compared to traditional devices, the ultra-low temperature SCR device has a flexible design and simple process flow. It does not require additional heating devices or modification of existing equipment, resulting in lower operation and maintenance costs. Additionally, the device is highly designable and adaptable to other flue gas, effectively controlling the comprehensive discharge of pollutants, indicating a broad market development prospect.

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