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Pilot-scale investigation of selective catalytic reduction (SCR) for cement kiln

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Abstract. Selective catalytic reduction (SCR) of NO_x is among the leading edge of the emerging hotspot of deNO_x technologies. However, most of the reported investigations were bench-scale study, which were limited to represent the performance of catalysts at real applications. With the successful construction of pilot scale (10000 Nm³/h) SCR system at a cement kiln, we systematically investigated the effect of NH₃/NO_x molar ratio, catalyst volume and system stability on NO_x removal efficiency. It is found that when the inlet NO_x concentration was at the range of 200 to 300 mg/m³, the corresponding outlet NO_x concentration was below 50 mg/m³ during 168 operating hours with ammonia emission below 0.98 mg/m³ at NSR of 0.89-1.0.

1. Introduction

Increasing deterioration of atmospheric environment has led to strict regulations to control the emissions of nitrogen oxides, which consequently stimulated a significant number of researches to derive some effective NO_x abatement technologies. Post-combustion NO_x abatement technologies have been demonstrated to be effective to deal with the stringent NO_x emission standard.

For the denitrification of cement industry, which is one of the largest fixed emission sources of atmospheric pollutants, there are three methods presently including low NO_x combustion technology^[1,2], selective non-catalytic reduction (SNCR) method^[3,4] and selective catalytic reduction (SCR) method^[5,6]. Since the efficiency of low NO_x combustion technology and SNCR method is too low to meet the emission standard of air pollutants for cement industry, the SCR method with high denitrification rate, mature technology and no harmful product formation, has become the main method for denitrification in power plant. However, the catalysts are easy poisoning and clogging when used in cement kiln, because of high dust concentration and alkali metal content in the exhaust gas from cement kiln. In these perspectives, the present study developed catalyst to remove nitrogen oxide in pilot-scale with high NO_x removal efficiency with low ammonia emission at proper NSR ratio.



2. Experimental setup

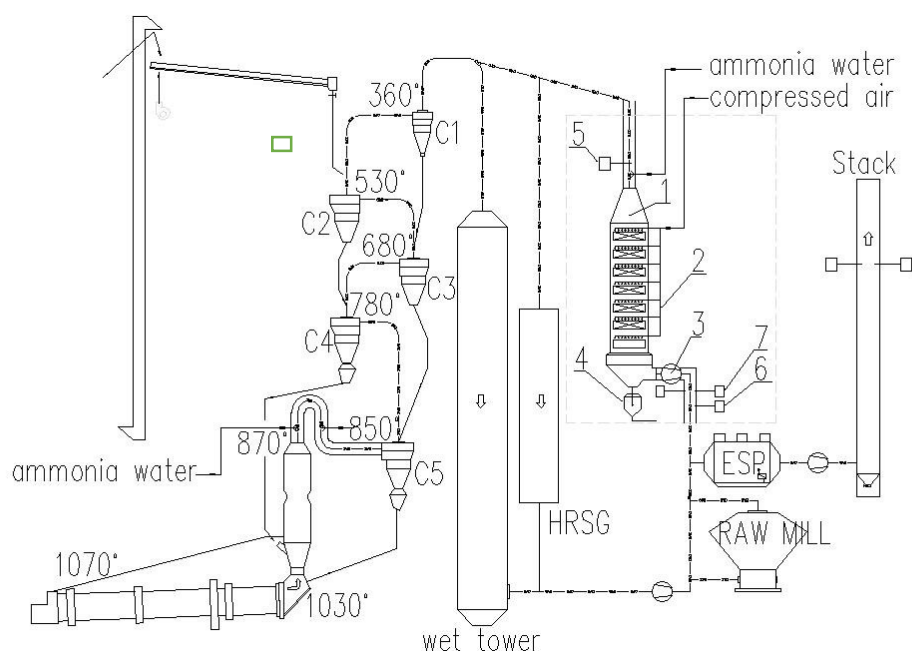


Figure 1. Structural design and schematic of pilot-scale test

1. SCR reactor; 2. steam soot blower; 3. induced draft fan; 4. silo pump; 5. temperature detector; 6. continuous emission monitor system (CEMS); 7. ammonia detector

A schematic diagram of the experimental system used in this investigation is shown in Figure 1. The pilot-scale configuration of SCR was installed downstream of SNCR system, whose gas was introduced from the location after preheater of C1 colone with temperature of 310-350 °C. Continuous Emission Monitor System (CEMS-1), thermal-couples, and pressure gauge were installed at the inlet duct to obtain the concentrations of inlet NO_x and O₂, temperature (*T*) and pressure (*P*), respectively. The main parameters of the clean exhaust gas, such as [NO_x], [O₂], *T*, and *Q*, were measured by CEMS-2, which was installed at the outlet duct. All these parameters were sent to the control system to calculate how much ammonia solution should be injected into the reactor. Thus a regulating valve combined with a liquid flow guage were necessary to maintain the correct feed rate of ammonia. The injected ammonia solution was vaporized and dispersed by the flue gas, and then passed through guide vanes to mix into more uniform and well-distributed. The SCR reactor inner channel is B970 mm×L1800 mm with total height of 28 m, in which flue gas passed through the inlet, guide vanes, and five catalysts layers in turn.

3. Results and discussion

3.1. Effect of NH₃/NO_x molar ratio

Under the designed conditions (gas flow of 10000 Nm³/h, inlet NO_x concentration of 200-300 mg/m³), Figure 2 shows the effects of NH₃/NO_x molar ratio on NO_x removal efficiency. It can be seen that when the NH₃/NO_x molar ratio less than 0.89, NO_x removal efficiency was increased rapidly, but over 0.89 the efficiency increased from 88.5 % to 90.2 % with ammonia emission raised greatly from 1.25 mg/m³ to 5.72 mg/m³. This phenomenon is mainly due to the number of active sites on catalyst surface. When NH₃ concentration is low, with the increase of NH₃ concentration in gas phase, more NH₃ was adsorbed to the active sites of the catalyst and reacted with NO_x. But when the NH₃ concentration

is high in gas phase, there are enough NH_3 which can react with NO_x . Because of the limitation of active sites on catalyst surface, the residual NH_3 cannot react with NO_x . Then, the NO_x removal is no longer be influenced by the concentration of NH_3 .

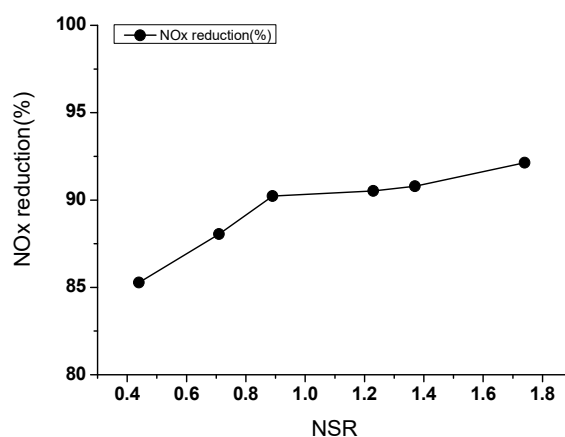


Figure 2. Effect of NSR on NO_x reduction

3.2. Influence of Catalyst Volume

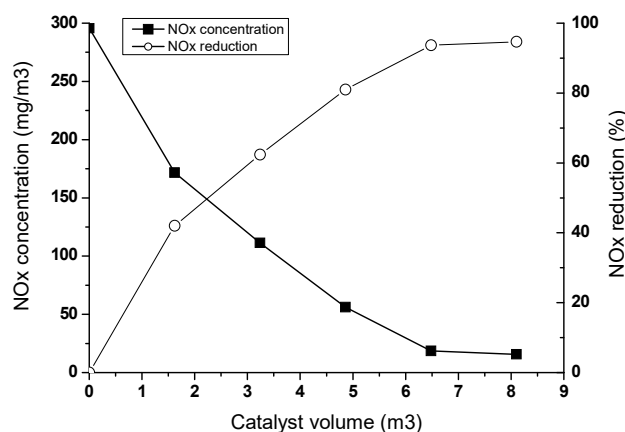


Figure 3. Effect of catalyst volume on NO_x reduction

There are 5 catalyst layers with total volume of 8.1 m^3 in the SCR system. Figure 3 illustrates the results of NO_x removal efficiency according to the loaded amount of catalyst attaching. It is clear that with the increased catalyst loading, NO_x removal efficiency increases proportionally. Since the cost of catalyst accounted for about 25%-35% in the combustion cost and above 50% in the operation cost, it's necessary to find reasonable catalyst volume in de NO_x process. From Figure 3, it can be obtained that one catalyst layer was needed to achieve the outlet NO_x concentrations less than 100 mg/m^3 , while 4 catalyst layers were needed to achieve outlet NO_x concentrations less than 50 mg/m^3 .

3.3. Stability Test

Figure 4 illustrates the results of NO_x removal efficiency vs. exposure time. It is found that when the inlet NO_x concentration was at the range of 200 to 300 mg/m^3 , the corresponding outlet NO_x concentration was below 50 mg/m^3 during 168 pilot operating hours. And the removal efficiency of NO_x can reach 91.0%. Meanwhile, the ammonia emission concentration was 0.98 mg/m^3 .

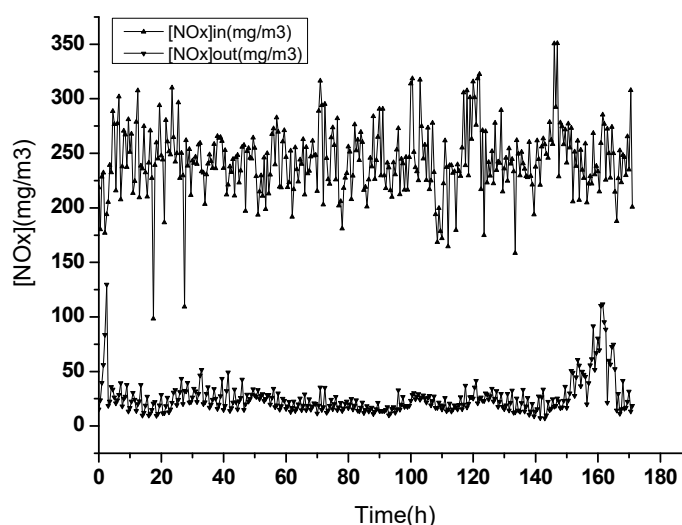


Figure 4. Effect of operating time on NOx reduction by SCR system for cement kiln

4. Conclusion

A pilot-scale SCR system was designed based on the typical characteristic of cement flue gas. The pilot was successfully operated with low NOx and NH₃ emission. And the NOx concentration was reduced by 91.0% removal efficiency with ammonia emission below 0.98 mg/m³ at NSR of 0.89-1.0. Performance tests of 168 operating hours confirmed that SCR is a suitable technology for deeply reduction of NOx in cement industry.

Acknowledgments

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