The development and application of SCR denitrification technology in power plant

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Abstract. In recent decades, the emission of the nitrogen oxides (NOX) has been increasing with the years of the thermal power plant. The environment pollution caused by the emission of quantities of nitrogen oxides became more and more serious, so people now put more emphasis on the control of the emission of the nitrogen oxides. Especially, our country and the society are paying more attention to the environment protection and the environment problems cannot be neglected. In this paper, we introduced the related research background of the technology of SCR denitrification which was as the symbol of the technology of the catalytic denitrification and discussed the reaction principles of the SCR denitrification and frequently used catalysts, the process of the technology, and the configuration. In the end, we pointed the way of the future research of the technology of the SCR denitrification.

1. Introduction
Nitrogen oxides (NOX) is a hypertoxic pollutant that will do harm to the human health and destroy the ozone layer and environment. The NOX mainly comes from the combustion of coal, petroleum, natural gas and other fossil fuels. The major chemical constituents of the NOX are NO and NO2. Moreover, 90% of them are NO.

To protect the environment and decrease the emission of NOX, all the governments make the principle and standard related to the emission of the NOX. Recently, the major measures to control the NOX which comes from the combustion are these three methods: the denitrification before combustion, the denitrification during combustion and the denitrification after combustion. Because of many advantages such as the non-formation of by-product and secondary pollution, the simple device structure and the operating reliability carried by the selective catalytic reduction (SCR), it is widely used in commercial application and has become the most universal used flue gas denitrification. Under the true conditions that the emission of NOX that is still increasing is much more than 500 tons per year and the opposite relationship between the environment protection and industrial production are shaper than any other times, the SCR as a symbol of flue gas denitrification not only protect the environment efficiently, but also keep the industrial production working well as before. Therefore, it’s reasonable of the SCR to be used as the dominate technology.

2. The control technology of NOX
To protect the eco-environment, the whole world is making effort to develop the advanced technology to decline the emission of NOX. And the denitrification can be classified into 3 types according to the lifecycle of combustion: the denitrification before combustion, the denitrification during combustion and the denitrification after combustion.
The technology of denitrification before combustion is that we use the low NOX flue to replace the previous one. However, for the high cost of the low NOX flue, it’s not common used in the practice of engineering.

The technology of denitrification during combustion usually adopts the low NOX technology as the ubiquitous way for it’s well-developed technology and the low cost. Nevertheless, the NOX removal efficiency is usually below 40%. The technology, which utilizes the NOx burners as its first step to decrease the half content of NOx in the flue, then uses the denitrification after combustion as the second step to complete the denitrification, is widely used in countries that are strict with the NOx emission such as Japan, Germany and other countries.

The technology of denitrification after combustion is called flue gas denitrification. The main technologies are SCR, SNCR, SCR/SNCR combined flue gas denitrification and are widely used in Japan, America, Germany and other countries. The SNCR denitrification technology is that the reductant like ammonia or urea are injected into the furnace then the reductant is decomposed into NH3 and next the NH3 react with the NOX, forming the innocuous N2 and H2O. The operating temperature is approximately 1000℃ and the NOX removal efficiency is between 25% and 50%. The technology of SCR denitrification is that decrease the reaction activation energy by adding the catalyst and then the NOX efficiency will reach up to about 95%. The operating temperature is around 400℃. The SCR/SNCR combined flue gas denitrification is that the escaping ammonia react with the unreacted NOX after the reductant is injected into the furnace to make the catalytic reduction more complete. The denitrification can reach up to 40%~80% [2-4].

3. The technology of the SCR denitrification

The technology of SCR denitrification is selecting catalytic reduction of the flue gas denitrification. The technology is that the ammonia or the appropriate nitrogen compounds which are blown into the SCR reactor reduce the NOX to the N2 and H2O under the catalysis of the metal catalyst. Because of the advantages such as lower operating temperatures, high NOX removal efficiency and the non-formation of the secondary pollution, the technology of SCR denitrification become the standard and major technology of the NOX emission. What’s more, the design of the structures of the technology of SCR denitrification is relatively simple, which is much more convenient to be applied in the industrial production. In addition, the technology of SCR denitrification has perfect compatibility to work with other technology, especially, the technology of desulfurization and the destruction of the dioxin-like compounds. [4,5]

4. The technical principle of SCR denitrification technology

4.1 The chemical reactions of SCR denitrification technology

There are many chemical reactions during the SCR denitrification technology. And the main chemical reaction of the denitrification is the oxidation-reduction reaction whose reductant is usually ammonia [5,6].

\[
\begin{align*}
4\text{NO} + 4\text{NH}_3 + \text{O}_2 & \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O} \\
6\text{NO} + 4\text{NH}_3 & \rightarrow 5\text{N}_2 + 6\text{H}_2\text{O} \\
2\text{NO}_2 + 4\text{NH}_3 + \text{O}_2 & \rightarrow 3\text{N}_2 + 6\text{H}_2\text{O} \\
6\text{NO}_2 + 8\text{NH}_3 & \rightarrow 7\text{N}_2 + 12\text{H}_2\text{O}
\end{align*}
\]

The main reaction always accompanying with three side reactions which will have negative influence on the main reaction: the oxidation of ammonia, the oxidation of sulfur dioxide, the formation of the ammonium salt [7].

4.1.1. The oxidation of ammonia
The oxidations of ammonia cause the decrease of the content of the ammonia and then in to meet the requirement of the removal rate of the NOX, more ammonia must be added to the reaction system. Secondly, with the oxidation of ammonia, the removal rate of the NOX will decrease following the volume of the catalyst, which is not enough to catalyze the NOX reacted with the succeeding ammonia [7].

4.1.2. The oxidation of sulfur dioxide

\[ 2\text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3 \]

The sulfur dioxide is oxidized to the sulfur trioxide and then the sulfur trioxide reacts with the catalyst and the flue informing the solid particles. That the solid particles deposit on the surface of the catalyst or into the inside of the catalyst will influence the life of the catalyst.

4.1.3. The formation of the ammonium salt

\[ 4\text{NH}_3 + 5\text{O}_2 \rightarrow 4\text{NO} + 6\text{H}_2\text{O} \]
\[ 4\text{NH}_4 + 3\text{O}_2 \rightarrow 2\text{N}_2 + 6\text{H}_2\text{O} \]

The NH4HSO4 and (NH4)2SO4 are formed by the reaction between the sulfur trioxide and the ammonia, which are the main ammonium salt. These compounds will condense and deposit in the flue making the catalyst deactivated. Moreover, these compounds will corrode the downstream equipment of the SCR system.

4.2 The catalysts of the SCR denitrification technology

The precious metal and the non-precious metal are always used in the SCR denitrification technology. The precious metal catalyst is platinum, palladium, rubidium and other precious metals that are all carried by the Al2O3 and other integral ceramics. However, For the low selectivity, these catalysts are not widely used before.

The non-precious metal catalyst occupies the major part of the catalyst of the denitrification technology and consist of the metal oxide catalyst and the zeolite catalyst. The transition metal catalysts are V2O5(WO3), Fe2O3, CuO etc., the main group metal catalysts are MgO, Al2O3 etc. and composite metal catalysts are Cu-Mg-Al, Cu-Co-Mg-Al etc. And TiO2, Al2O3, ZrO2, SiO2 and the active carbon are the main supports of all these catalysts.

The zeolite catalyst is that molecular sieve which is a kind of solid acid catalyst with plenty of microporous and has the advantages of good absorbability, reproducibility and heat stability. Hence, it takes an important role in the developing catalyst.

5. The systematic constitution of the technology of SCR denitrification

5.1 The main process of the technology of SCR denitrification

The liquid form of the reductant (ammonia as an example) is transported by ammonia-carrying truck and then is stored in the anhydrous ammonia tank. Before injected into the flue gas of the SCR denitrification system, the reductant must be evaporated by the ammonia evaporator. The next step is that the ammonia is mixed with the air in the ammonia and air mixer. After mixed, the mixed flue is injected into the flue gas of the upstream device by ammonia injection grid. At last, the reductant reacts with the flue gas in the SCR reactor catalyzed by the catalyst to remove the NOX in the flue gas. The progress is shown in Figure 1.
5.2 The concrete systematic constitution of the technology of SCR denitrification

The systematic constitution of the technology of SCR denitrification is consist of the flue gas system, the storage and supply system of the ammonia, the ammonia and air mixer system, the ammonia injection system, the SCR reactor system, soot blower system and other systems. The Figure 2. is the diagram of the systematic constitution of the technology of SCR denitrification.

5.2.1. The flue gas system

The flue gas system is a kind of pipe among the outlet of economizer, the inlet of the SCR reactor, the outlet of the SCR reactor to make the flue gas flow smoothly.
5.2.2. The storage and supply system of the ammonia

The ammonia is transported by the ammonia-carrying truck in the form of liquid and then is stored in the anhydrous ammonia tank. During the SCR denitrification, the liquid ammonia is evaporated by the ammonia evaporator and then the liquid ammonia buffer makes the input of the ammonia stalely. In the end, the ammonia flow into the ammonia and air mixer to be mixed well. One point that should be noticed is to make the whole system safe every unit of the storage and supply system of the ammonia must be equipped with the ammonia detector and exhaust system, to prevent the accident caused by the ammonia slip.

5.2.3. SCR reactor system

![Diagram of SCR reactor system](image)

**Figure 3.** The diagram of the SCR reactor system [9]

The diagram of the SCR reactor system is shown in Figure 3. The SCR denitrification reactor is the most vital part of the SCR denitrification, which is the place for the ammonia and NOX to react with each other under the catalysis of the catalyst. The approximate progress is that the flue contains the nitrogen oxides flow in the reactor from the inlet, and the ammonia is injected into the SCR reactor from another pipe simultaneously, then the mixed gas reacts with each other during passing through the catalyst that be set layer by layer. Eventually, the gas that has react completely and incompletely is exhausted from the outlet. It is notable that in the reactor, the new catalyst is always set on the place that the reserved catalyst should place. By using this method, not only can we decrease the replacement of the catalyst but also trim the cost of the replacement of the catalyst.

6. The configuration of the technology of SCR denitrification

There are two installation locations for the SCR reactor in the chimney of the boiler: the high-dust configuration and the tail-end configuration. Figure 4. is the diagram.
Figure 4 The diagram of the high-dust configuration and the tail-end configuration [5]

The front picture is the high-dust configuration. This configuration is that the reactor is placed before the air preheater about 350 centigrade. The fly dust and the sulphur dioxide all go through the reactor and the temperature is very high. This reactor applies to work in the high-dust environment.

The following is the tail-end configuration, it places the reactor after the smoke desulfurize device (belonging to the economizer bypass) and filter. In this way, the reactor can work in the non-dust and non-SO2 environment, hence it not only solves the erosion of the device and the blockage of fly dust to the reactor, but also makes the catalyst avoid being polluted. The disadvantage of it is that the boiler’s flue gas temperature is too low. As a result, we must install the extended combustor in the chimney, and then more energy and money need to be used.

7. Conclusion

With development of the society, the demand of the power supply is increasing, the contradiction with environment pollution is also becoming more and more severe. Under the pressure of the environment, all the countries are strict with the standards of the emission of NOX produced by coal-fired power plant. Therefore, the technology of the SCR denitrification is in the overall popularization. And it’s high time that we make efforts to optimize the device structures, and to conduct research about the optimal plan and figure out the law. Meanwhile, optimizing the devices that we have had is also very important. In this paper, we found that, enlarging the contact areas of the catalysts and the mixed gas in reasonable range in the SCR reactor of the technology of SCR denitrification, as well as searching for the new efficient stable and more selective catalysts, for instance, the zeolite catalyst, are the effective optimal plans we can have. Moreover, investigating the optimal combinations of the technology of SCR denitrification and the technology of denitrification during combustion are also the effective ways.

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