Intelligent Calculation Method and Algorithm Optimization of Consumption Reducing for SCR and SNCR in Denitration System

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Abstract. Since the environmental laws have been more and more strict about pollutants emissions of thermal power plant, SNCR and SCR system seems to be typical configuration. However the ammonia consumption calculation differs from different designers. In this paper the popular and experienced calculation method is introduced for thermal power plant dinitration system.

1. Introduction
For the new built thermal power plant, the $NO_x$ emission limits is 50 mg/Nm³ in most of the local standards. SCR (Selective Catalytic Reduction) system and SNCR (Selective non-Catalytic Reduction) system, or the combined SNCR+SCR systems seem to be typical design for thermal power plant. However in the preliminary design, the SCR/SNCR supplier has not been involved and the ammonia or other reducing agent consumption differs from different designers.

For the SCR system, there is a Power Industry Standard [1] DL/T 5480-2013, Technical Code for the Design of Flue Gas Denitration of Fossil Fired Power Plant, where the ammonia calculation has been included. While for the SNCR system, the ammonia consumption depends more on experience and that’s why the amount differs a lot. In this article, the calculation of ammonia consumption is introduced for SNCR, SCR and SCR+SNCR systems.

2. Ammonia consumption for SCR system
According to GB13223-2011 [2] Emission Standard of Air Pollutants for Thermal Power Plant, the emission test method is based on the stabilized composition $NO_2$ in the $NO_x$.

In the boiler technical specification, the guaranteed $NO_x$ discharged value ($C_1$) out of furnace is usually the equivalent $NO_2$ concentration at standard condition and actual $O_2$ percentage. In the actual flue gas composition test, NO takes up of about 95% and $NO_2$ of 5%.

To get the actual NO and $NO_2$ concentration out of furnace, the following formula [3] is used.

\[ C_{NO} = \frac{C_1 \times 0.95 \times 30}{46} \]
\[ C_{NO2} = C_1 \times 0.05 \]

In which, $C_1$ refers to the guaranteed $NO_x$ emission from the boiler supplier, standard condition, actual $O_2$;
\(C_{NO}\) refers to actual NO concentration out of furnace, standard condition, actual \(O_2\), dry basis;
\(C_{NO2}\) refers to actual \(NO_2\) concentration out of furnace, standard condition, actual \(O_2\), dry basis;
If the guaranteed \(NO_x\) concentration is at 6\%\(O_2\) (\(C_{NOx6\%O2}\)) condition, a transformation shall be done according to the following formula:

\[
C_{NOx} = C_{NOx6\%O2} \times \frac{21 - r_{O2}}{21 - 6}
\]

The main reactions in SCR system is as follows:

\[
4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O
\]
\[
2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O
\]

The ammonia consumption \(W_a\) is calculated according to DL/T 5480-2013.

\[
W_a = \left( \frac{V_q \times C_{NO}}{1.76 \times 10^6} + \frac{V_q \times C_{NO2}}{1.35 \times 10^6} \right) \times m
\]

\(W_a\), ammonia consumption (kg/h);
\(V_q\), flue gas flow rate at SCR reactor inlet, standard condition, actual \(O_2\) (Nm³/h);
\(C_{NO}\), NO concentration in inlet flue gas, standard condition, actual \(O_2\) (mg/Nm³);
\(C_{NO2}\), \(NO_2\) concentration in inlet flue gas, standard condition, actual \(O_2\) (mg/Nm³);
\(m\), mol ratio of ammonia and \(NO_x\),

\[
m = \frac{\eta_{NOx}}{100} + \frac{\gamma_b}{22.4} \frac{22.4}{30 \times 10^6 + \frac{C_{NO}}{23}}
\]

\(\eta_{NOx}\), SCR efficiency;
\(\gamma_b\), escaped ammonia percentage(μL/L);
For SCR system, \(\gamma_b\) is usually around 3 to 5 ppm wherefore mol ratio of ammonia and \(NO_x\) is approximate to SCR efficiency.

3. Ammonia consumption for SNCR system
In SNCR system, urea is the common reducing agent instead of ammonia [4]. Since NO takes up more than 95\% in the flue gas and the reaction of \(NO_2\) and ammonia happens slowly without catalyst, the main reaction in SNCR system is as follows:

\[
2NO + CO(NH_2)_2 + \frac{1}{2}O_2 \rightarrow 2N_2 + CO_2 + 2H_2O
\]

The ammonia consumption \((W_a')\) for SCR is calculated as follows:

\[
W_a' = \left( \frac{V_q \times C_{NO} \times 60}{30 \times 10^6} \right) \times NSR_n
\]

\(W_a'\), ammonia consumption for SNCR (kg/h);
\(V_q\), flue gas flow rate at SCR reactor inlet, standard condition, actual \(O_2\) (Nm³/h);
\(C_{NO}\), NO concentration in inlet flue gas, standard condition, actual \(O_2\) (mg/Nm³);
\(NSR_n\), mol ratio of urea and NO;
Several factors, such as $NO_x$ concentration in the flue gas, reaction time, the flue turbulence, ammonia escape ratio and so on, affect the value of ‘$NSR_n$’. So it is difficult to define the value of $NSR_n$ precisely. According to the chemical reaction, 1 mole urea could react with 2 mol NO. However because of the complexity of this reaction process, the actual urea consumption is higher than the theoretical amount.

According to engineering experience, the SNCR efficiency hardly increase when $NSR_n$>2 [5].

### Table 1. $NSR_n$ and SNCR efficiency [5].

| NO. | SNCR EFFICIENCY | $NSR_n$ |
|-----|-----------------|---------|
| 1   | 24              | 0.8     |
| 2   | 35              | 1.25    |
| 3   | 38              | 1.5     |
| 4   | 40              | 2.0     |

The usual applied SNCR efficiency is around 50% and the $NSR_n$ is recommend between 2 and 3 in the preliminary design. A common misunderstanding is that $NSR_n$ is approximate to SNCR efficiency, which lead to big deviation from the real ammonia consumption.

### 4. Ammonia consumption for SNCR+SCR system

In some conditions such as CFB boilers, biomass power plant and so on, both SNCR and SCR system are equipped and urea is always used as reducing agent in SNCR+SCR systems. The urea is sprayed into the furnace as part of SNCR system where urea is pyrolysised to be ammonia, which reacts with $NO_x$ in the flue gas. Since the amount of urea is supposed to be larger than the chemical equivalent, the ammonia escape in SNCR is also bigger. Then the escaped ammonica reacts with $NO_x$ in SCR system. And in total, the whole ammonia escape percentage keeps around 3 to 5 ppm, which is similar to SCR system.

The following formula is used for calculation of urea consumpiton:

$$W'_{ur} = \frac{V_q \times C_{NO1} \times 60}{30 \times 10^6} \times NSR_n + \frac{V_q \times C_{NO2} \times 60}{30 \times 10^6} \times m'$$

$$C_{NO2} = C_{NO1} \times (1 - \eta_{SNCR})$$

$$m' \approx \eta_{SCR}$$

In which, $W'_{ur}$ refers to the amount of urea consumed in SNCR+SCR system, kg/h;
$V_q$, flue gas flow rate at SCR reactor inlet, standard condition, actual $O_2$ (m$^3$/h);
$C_{NO1}$, NO concentration before the urea nozzle, standard condition, actual $O_2$ (mg/Nm$^3$);
$NSR_n$, mol ratio of urea and NO in the SNCR system;
$C_{NO2}$, NO concentration at the inlet of SCR system, standard condition, actual $O_2$ (mg/Nm$^3$);
$m'$, mol ratio of urea and $NO_x$,
$\eta_{SNCR}$, SNCR efficiency;
$\eta_{SCR}$, SCR efficiency;

The calculation method above also could be applied in municipal waste incineration power plant but the $NSR_n$ value shall be modified according to good project experience.

### 5. Calculation example

One thermal power plant is with the flue gas flow rate of 175000m$^3$/h, and 140°C in the furnace outlet. The calculation result of SCR and SNCR urea consumption is shown in Table 2 and Table 3.
Table 2. Calculation Result of SNCR

| NO. | Item                          | Unit       | Data  |
|-----|-------------------------------|------------|-------|
| 1   | Flue gas flow rate            | m³/h       | 175000|
| 2   | Flue gas temperature          | ℃          | 140   |
| 3   | Flue gas flow rate (standard condition) | Nm³/h | 115678|
| 4   | NO concentration (actual O₂,dry basis) | mg/Nm³ | 200   |
| 5   | $NSR_n$                       | /          | 2     |
| 6   | $\eta_{SNCR}$                 | %          | 40    |
| 7   | Urea consumption              | kg/h       | 116   |

Table 3. Calculation Result of SCR

| NO. | Item                          | Unit       | Data  |
|-----|-------------------------------|------------|-------|
| 1   | Flue gas flow rate            | m³/h       | 175000|
| 2   | Flue gas temperature          | ℃          | 140   |
| 3   | Flue gas flow rate (standard condition) | Nm³/h | 115678|
| 4   | Guaranteed NOx concentration (actual O₂,dry basis,standard condition) | mg/Nm³ | 300   |
| 5   | $C_{NO}$                      | mg/Nm³     | 186   |
| 6   | $C_{NOx}$                     | mg/Nm³     | 15    |
| 7   | $\eta_{SCR}$                  | %          | 88    |
| 8   | Ammonia escaped percentage    | ppm        | 5     |
| 9   | mol ratio of ammonia and $NO_x$ | /       | 0.913 |
| 10  | Ammonia consumption           | kg/h       | 13    |
| 11  | Urea consumption              | kg/h       | 23    |

6. Conclusion

The calculation method is not complex, however in the preliminary design, big deviation happens between calculated amount of ammonia and the actual consumption. There are two common misunderstandings in the design stage:

1) The NO Concentration in the flue gas: the guaranteed $NO_x$ emission provided by boiler manufacturers is the stable $NO_2$ concentration required in GB13223-2011. It has to be converted to actual NO and $NO_2$ concentration at standard condition and actual $O_2$ concentration.

2) The mol ratio of $NO_x$ and ammonia: for SCR system it approximates to SCR efficiency while for SNCR, it is an experienced value.

In summary, the ammonia consumption calculation of SCR system shall apply to methods in Power Industry Standard DL/T 5480-2013, Technical Code for the Design of Flue Gas Denitration of Fossil Fired Power Plant, which is also introduced in this article. For SNCR system, the reaction of NO and NH₃ is considered as the main reaction and the mol ratio of ammonia and NO is recommended between 2 to 3.

References

[1] Technical Code for the Design of Flue Gas Denitration of Fossil Fired Power Plant, DL/T 5480-2013.
[2] Emission Standard of Air Pollutants for Thermal Power Plant, GB13223-2011.
[3] Yeqing Zhu, Yuan Bo, Jianming Xue, Zhonghua Li, Electric Power Technology and environmental protection, 2014,Commun. 30,pp.44.
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[5] Yongjian Ye, Guo Yuan, Guanping Cai, Aiping Ma, Dongmei Wu, Electric Power Survey & Design, 2009-April, pp.56.