A Combination of SNCR Technologies
Selective Flue Gas Cooling and TWIN-NO\textsuperscript{x}

- **Selective Cooling** optimizes flue gas temperatures for the SNCR process at the injection positions. NO\textsubscript{x} reduction rates are improved and the consumption of reagents is reduced.

- The TWIN-NO\textsuperscript{x} process produces excellent results by combining the advantages of the reagents ammonia water and urea solution.

**Combining Selective Cooling and TWIN-NO\textsuperscript{x}**

- Low investment costs
- Reduced consumption of reagents
- Easy retrofitting
- High availability
- Improved NO\textsubscript{x} reduction rates
- Safe compliance with new EU standards

Mehldau & Steinfath Umwelttechnik GmbH, Alfredstr. 279, 45133 Essen • Tel. +49 201 43783-0
Fax +49 201 43783-33 • zentrale@ms-umwelt.de • www.ms-umwelt.de
Complying with the New EU NO\textsubscript{x} Emission Standards
– Combining Advanced SNCR Technologies –

Bernd von der Heide

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The valid emission limits in the EU, for example NO\textsubscript{x} emissions of waste-to-energy plants and combustion plants fired with other fuels like coal, oil, biomass, etc. have to be adjusted from time to time reflecting the progress of technical developments as well as environmental concerns.

A technology which is best suited to reach a high level of environmental protection by keeping a reasonable cost/benefit ratio is called Best Available Technology (BAT).

This paper shows how the improvements that have been achieved with the technology of Selective Non-Catalytic NO\textsubscript{x} Reduction (SNCR) can be applied not only in new but also in existing combustion plants which have been operating for many years with an older DeNO\textsubscript{X} system.

1. Future NO\textsubscript{x} emission limits for combustion plants

BREF is the abbreviation for Best Available Technique REFerence Document, or in short: BAT reference Document. In German a BVT leaflet defines the Best Available Technique corresponding to BREF.

The Final Draft of the BVT leaflet for waste-to-energy plants defines the NO\textsubscript{x} emission requirements which are shown in Table 1.

When the first SNCR plants were put into operation in the 80s of the last century, the NO\textsubscript{x} limits of < 200 mg/Nm\textsuperscript{3} in accordance with the German Federal Emission Control Act (17. BImSchV) could reliably be complied with although the technical configuration
was relatively simple. This was owed to the fact that the combustion plants were mostly operated at full load. Therefore, the variation of flue gas temperatures in the first boiler pass stayed within an acceptable range. Furthermore, ammonia slip was not of major concern at that time. According to TA Luft, another German regulation, the limit was < 30 mg/Nm³ so that an SNCR plant equipped with only one injection level was sufficient to fulfil the requirements imposed by the regulators.

Figure 1 shows the concept and the functions of a typical first generation SNCR plant with urea solution as reagent which used to be operated in combustion plants according to 17. BImSchV, reaching a NOx reduction of up to 60 %. Depending on the requirements the SNCR plants are equipped with one or two injection levels.

In response to load changes and/or to the flue gas temperatures the injection levels can be switched to follow the average flue gas temperatures in the injection levels.

In order to follow major temperature variations and imbalances which typically arise during operation, to reduce NH₃ slip and to optimize the consumption of reagent, two injection levels proved to be most effective in waste-to-energy plants which were equipped in the 1990s in accordance with the 17. BImSchV (Figure 2). These two injection levels are switched on or off depending on the average temperatures measured with thermocouples at the boiler roof in the first flue gas path.

Table 1: Final draft of the BVT leaflet for Waste-to-Energy plants

<table>
<thead>
<tr>
<th>Emissions</th>
<th>Unit</th>
<th>New plants</th>
<th>Existing plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>mg/Nm³</td>
<td>&lt; 120</td>
<td>&lt; 150</td>
</tr>
<tr>
<td>CO</td>
<td>mg/Nm³</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
</tr>
<tr>
<td>NH₃ slip</td>
<td>mg/Nm³</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
</tr>
</tbody>
</table>
Complying with the New EU NO\textsubscript{x} Emission Standards – Combining Advanced SNCR Technologies

Under favourable operating conditions, when homogeneous fuel is used and the boiler is operated at constant load, NO\textsubscript{x} clean gas values of < 150 mg/Nm\textsuperscript{3} can be achieved with this concept. However, imbalances of the flue gas temperatures and the flue gas flow may affect NH\textsubscript{3} slip and consumption of reagent. In case major temperature imbalances are found between the front and the rear walls of the furnace activating only one half of the injection level – front or rear – is a very successful solution.

Figure 2: Changing injection levels following temperature imbalances

Advantages of changing of individual lances and/or injecting of cooling water versus standard SNCR system
- higher efficiency
- lower NO\textsubscript{x} emission
- NH\textsubscript{3}-slip < 10 mg/Nm\textsuperscript{3}
- reduced reagent consumption
- lower CO emissions

Figure 3: Changing of individual lances with and without selective cooling versus standard SNCR

However, the concepts described above are not sufficient for modern plants which are operated in accordance with the current BREF standards.

The next step in the technological progress was that individual lances or groups of lances were activated or deactivated in order to make sure for any location that the reagent is
always injected into the range of the temperature window where NO\textsubscript{x} reduction, NH\textsubscript{3} slip and consumption of reagent reach their optimum (Figure 3).

For optimum performance both the flue gas composition and the flue gas temperatures are essential for controlling the SNCR process. Where the optimal temperature window for SNCR lies depends very much on the flue gas composition (Figure 4). This means, for example, that CO shifts the temperature window towards lower temperatures, while SO\textsubscript{2} has the contrary effect. The optimal temperature window for waste-to-energy is located between 980 to 1,030 °C, for fluidized bed boilers where CO is generally high it is below 900 °C, and for furnaces with a high SO\textsubscript{2} content in the flue gases it is up to 1,050 °C. Depending on the desired performance of the SNCR one of the following temperature measurement methods could be applied:

- Thermocouples are very sensitive to the influence of heat radiation from the furnace, as well as to cold radiation from the boiler walls and the heat exchangers. In the past they were installed in SNCR plants which had to comply with 17. BlmSchV only, but due to the described limitations this method does not meet the requirements of more stringent NO\textsubscript{x} limits.

- The measurements with suction pyrometers are quite accurate and are mainly used for manual temperature measurements to verify the continuous measurement systems. They are not suitable for continuous measurements since their handling is time-consuming.

- Broad experience has been gathered with acoustic gas temperature measurement systems which have proven to be suitable for the most demanding applications. This method is therefore recommended where NO\textsubscript{x} emission values < 100 mg/Nm\textsuperscript{3} and NH\textsubscript{3} slip < 10 mg/Nm\textsuperscript{3} have to be guaranteed.
Since several years spectral pyrometers have been put into operation increasingly. The results achieved with this optical method show that – in relation to acoustic measurements – comparable degrees of NO\textsubscript{x} reduction can be obtained at lower cost.

Figure 5: Methods of contact-free temperature measurement

Both methods, the optical and acoustical temperature measurement, have advantages and disadvantages (Figure 5 and 6): During the acoustic measurement each transceiver at the boiler wall communicates in turns with all the other transceivers. Thus, a multitude of temperature paths is formed which provide a high resolution.

In contrast, each spectral pyrometer measures one path only which results in a lower resolution. The advantage of this method is that it provides sufficiently accurate temperature measurements even in areas which are otherwise difficult to access, for example between the heat exchangers and individual injection lances.

At the waste-to-energy plant Wijster in the Netherlands, three SCR units of the plant were shut down and replaced by SNCR systems. In response to the ambitious requirements (NO\textsubscript{x} reduction from approximately 330 to 350 mg/Nm\textsuperscript{3} to $< 60$ mg/Nm\textsuperscript{3} and an NH\textsubscript{3} slip $< 10$ mg/Nm\textsuperscript{3}) three injection levels with six lances each were installed. In this concept each lance is activated individually depending on zone temperatures.

Figure 6:

Methods of contact-free temperature measurement – acoustic (left), optical (right)
After determining the temperature profile, it is divided into sections and can be assigned to a certain lance or group of lances which can then be activated depending on the flue gas temperatures. Even when there are sudden changes in the flue gas temperatures this method ensures that the reagent is injected into those areas where optimum results regarding NO\textsubscript{x} reduction, NH\textsubscript{3} slip and consumption of reagent can be achieved.

The results that were measured in continuous operation of several combustion plants show that NO\textsubscript{x} clean gas values of < 100 mg/Nm\textsuperscript{3} and an NH\textsubscript{3} slip of < 10 mg/Nm\textsuperscript{3} can be guaranteed and even noticeably better results are possible under favourable operating conditions.

### 2. Retrofitting or refurbishing of existing SNCR systems

Older SNCR plants which have been operated successfully for 20 years or more, have a limited ability to meet the recent requirements or cannot meet them at all. Considering the future NO\textsubscript{x} limits of < 100 mg/Nm\textsuperscript{3}, NH\textsubscript{3} slip < 5 mg/Nm\textsuperscript{3} and minimized consumption of reagent, these plants need to be refurbished.

Measures for refurbishing include the extension of the system to three injection levels, changing of individual lances and acoustic or optical pyrometers for the continuous measurement of the flue gas temperatures (Figure 8).

Depending on age and condition of the SNCR plant it may be feasible to include the additionally needed armatures in the existing mixing and metering modules. In most cases, however, this cannot be recommended, and often it is not possible either since the additional components need more space than is available in the mixing and metering modules of the simple types of first generation SNCR. If space in the modules is too restricted, this may hinder the necessary access for maintenance works and should therefore be taken into consideration as well.
Sometimes the limited space in the boiler house does not allow for the installation of a bigger mixing and metering module. In such a case a possible solution may be to install the additional instruments between the module and the injection lances directly on the boiler walls.

Even if the further use of the existing components (e.g. control valves, pressure retaining valves, ball valves etc.) is intended, in many cases, it makes more sense to use new and larger cabinets and to complement them with new armatures. Mostly it is easier and more cost-efficient to set up the mixing and metering modules in bigger new cabinets in the workshop than to use the old smaller cabinets for the mounting of additional parts at site (Figure 9 and 10).
3. Adaptation to changed operating conditions

Many waste-to-energy plants are operated at a capacity range which is higher than originally designed for. As a result the flue gas temperatures are higher than they were at the time when the plant was first put into operation. Consequently, the optimum temperature range for the SNCR process is often shifted to the second pass, especially at the end of the service interval and when ammonia water is used as the reagent. With the rising temperatures the reagent is increasingly burnt to NO\textsubscript{x}. The required NO\textsubscript{x} reduction can, therefore, in many cases only be achieved with a higher consumption of reagent and an increased ammonia slip (Figure 11).

A possible solution is the installation of additional injection lances in the second pass which can be activated when the flue gas temperatures are too high. Should this not be possible, the same effect can be realized by injecting additional cooling water beneath the hottest lances of the highest injection level (Figure 12).

![Figure 11: Technical solutions when flue gas temperatures are too hot](image)

Problem: Flue gas too hot at the exit of 1\textsuperscript{st} pass

Solution 1: Additional injection level

Solution 2: Selective cooling

![Figure 12: Principle of selective cooling](image)
Relevant results and experiences with this method, protected by patent as Selective Cooling, showed in many cases a significant improvement of NO\textsubscript{x} reduction and the consumption of reagent. Selective Cooling cools the flue gases locally and temporarily. The major advantage of this method is that even at high boiler loads and flue gas temperatures, i. e. the complete load range, by changing individual lances injection is possible in the areas with optimum flue gas temperatures which are free of installations at the end of the furnace. This means that costly modifications of the heat-exchangers can be avoided.

Another method which has performed well is the TWIN-NO\textsubscript{x} process which combines the benefits of both reagents, urea and ammonia, in such a way that the effective temperature window is practically expanded (Figure 13 and 14).

This means that the highly volatile ammonia water is applied at low loads where the ammonia is released immediately and can react with NO\textsubscript{x}. When using urea solution, the reaction is delayed because the NO\textsubscript{x} reduction can only begin after the process water has evaporated and the urea molecules have been decomposed to NH\textsubscript{2} radicals and CO. Figure 14 shows a simplified process diagram of an SNCR plant which can be operated alternatively with urea solution or ammonia water as well as with a mixture of both reagents.
4. Results and practical experiences

The results and experiences with SNCR systems which have been retrofitted show that the future emission limits for NO\textsubscript{x} and ammonia can be met reliably.

![Diagram showing emission levels](http://ikw-ruedersdorf.de/emissionswerte.htm)

**Figure 15:** Emission levels – IKW Rüdersdorf


![Diagram showing emission levels](http://www.bisalzbergen.de/2016ZusammenfassungMVAwerte.pdf)

**Figure 16:** Emission levels – Waste-to Energy plant Salzbergen

The combustion plants in Salzbergen (municipal waste) and Rüdersdorf (refuse derived fuels) have been retrofitted and safely comply with the present regulations of $\text{NO}_x < 150 \text{ mg/Nm}^3$ and $\text{NH}_3 < 5 \text{ mg/Nm}^3$, as can be seen from the results shown in Figure 15 and Figure 16.

These and other plants, which are presently being retrofitted, require relatively little efforts in order to enable them to guarantee $\text{NO}_x$ levels $< 100 \text{ mg/Nm}^3$.

5. Comparing SCR to SCNR under energy and environmental aspects

In the waste-to-energy plant in Wijster, Netherlands, the existing SCR plant was replaced with an SNCR system in order to save operating costs (Figure 17). The SCR was installed downstream a wet flue gas cleaning system. The pressure drop across the heat-exchangers, the mixer, the flue gas ducts, and the catalyst elements amounted to approximately 25 mbar. To overcome the pressure drop, a blower with an electrical consumption of 250 kW per combustion line was required, whereas this additional energy is not needed in an SNCR plant. The temperature loss of the flue gas over the heat exchanger was about 30 K. The power required to raise the temperature again, was provided by gas burners consuming 2,200,000 m³ of natural gas per year and per plant. After removing the three catalysts the flue gas temperature at the stack decreased from 150 °C to approximately 95 °C. [3]

Although the utilization of ammonia water is less efficient in SNCR than in SCR plants, the total amount of all operating costs is much lower in SNCR plants.

![Diagram of waste-to-energy plant](image)

**Figure 17: Waste-to-Energy plant Wijster after retrofitting**


Also from the environmental point of view the SNCR technology appears in a positive light: Consuming less energy also means reducing emissions like $\text{CO}_2$ while the $\text{NO}_x$ emissions with SNCR are on the same level as with SCR.
As opposed to that, an SCR plant produces additional CO₂ emissions of 15,000 t/h just because it consumes a lot of additional energy for the generation of electricity which is needed for the higher blower capacity and for the gas-fired duct burners (Figure 18).

Table 2: Operating data – SCR versus SNCR (per line)

<table>
<thead>
<tr>
<th>operating data</th>
<th>unit</th>
<th>SCR NH₄OH</th>
<th>SNCR NH₄OH</th>
</tr>
</thead>
<tbody>
<tr>
<td>throughput of waste</td>
<td>t/h</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>flue gas volume flow</td>
<td>Nm³/h, tr.</td>
<td>100,000</td>
<td>100,000</td>
</tr>
<tr>
<td>operating hours</td>
<td>h/a</td>
<td>8,000</td>
<td>8,000</td>
</tr>
<tr>
<td>NOₓ raw gas concentration</td>
<td>mg/Nm³</td>
<td>330</td>
<td>330</td>
</tr>
<tr>
<td>NOₓ clean gas concentration</td>
<td>kg/h</td>
<td>45</td>
<td>50</td>
</tr>
<tr>
<td>NOₓ reduction per line</td>
<td>kg/h</td>
<td>28.5</td>
<td>28</td>
</tr>
<tr>
<td>NOₓ reduction (three lines)</td>
<td>t/a</td>
<td>684</td>
<td>672</td>
</tr>
<tr>
<td>ammonia water 24.5 % (three lines)</td>
<td>Nm³/h</td>
<td>800</td>
<td>4,000</td>
</tr>
<tr>
<td>consumption of compressed air incl. agam</td>
<td>Nm³/h</td>
<td>–</td>
<td>500</td>
</tr>
<tr>
<td>consumption of deionized water</td>
<td>m³/h</td>
<td>–</td>
<td>1.2</td>
</tr>
<tr>
<td>additional electr. consumption of ID fan</td>
<td>MWh/a</td>
<td>6,100</td>
<td>–</td>
</tr>
<tr>
<td>CO₂ for additional energy (three lines)</td>
<td>t/a</td>
<td>12,000</td>
<td>–</td>
</tr>
<tr>
<td>consumption of natural gas</td>
<td>Nm³/a</td>
<td>6,600,000</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 2 indicates that operating costs for reducing one ton of NOₓ are by far higher when using SCR technology than they would be in an SNCR plant. From other studies it can be concluded that the investment costs for SCR are at least five times higher than for SNCR which clearly shows that an SNCR plant with its better cost/benefit ratio is more economical and therefore much more effective protecting the environment.

6. Summary and outlook

The results of several years of operation with a number of SNCR plants show that the current and future BREF standards can not only be met, but even exceeded in many cases. Many plants which have been operated for many years were retrofitted recently and comply now with the new standards.
The modification of an existing SNCR system is relatively easy: Generally, some extra lances, advanced temperature measurement systems and a modernized control system are sufficient.

It is known that the investment costs for SCR exceed those for SNCR, but – depending on the design of the individual projects – these costs can be five to ten times higher for SCR than for SNCR. Another well-known fact is that because of the chemical conditions in the SNCR process, the consumption of reagent is approximately three times higher than with SCR. However, it is usually not considered that this effect is by far compensated due to the savings of other consumables.

Furthermore, the SNCR process has been continuously developed and improved over the last years. It has reached a high technological standard and has widely found acceptance in the meantime, especially with regard to NO\textsubscript{x} reduction in the flue gas of small to medium sized combustion plants burning for example waste, refuse derived fuel, and biomass. Depending on the design of the plant it is possible to maintain emission limits of $< 100 \text{ mg/Nm}^3 \text{ NO}_x$ in clean gas and $\text{NH}_3$ slip $< 10 \text{ mg/Nm}^3$, particularly when taking into account the cost/benefit ratio, the SNCR technology is well-established and accepted as Best Available Technology (BAT) for NO\textsubscript{x} reduction.

7. Literature


Contact Person

Dipl.-Ing. Bernd von der Heide
Mehldau & Steinfath Umwelttechnik GmbH
Chief Executive Officer (CEO)
Management
Alfredstraße 279
45133 Essen
GERMANY
+49 20143783-0
zentrale@ms-umwelt.de