Tailor-made SNCR to Meet Future Emission Standards for Power Boilers

Bernd von der Heide
Mehldau & Steinfath Umwelttechnik GmbH
Germany

1. Introduction

When the SNCR process was introduced in the eighties of the last century the focus was directed towards applying this low cost technology mainly in combustion plants. NO_x reduction rates of only 40 – 50 % were required. The usual temperature imbalances in these types of combustion plants did not cause any major problems. For higher NO_x reduction rates, however, the SNCR process was considered insufficient, and the SCR technology was usually applied.

After the turn of the millennium more stringent requirements have been introduced step by step. Emission levels of NO_x < 200 mg/Nm³ and NH_3 slip < 30 mg/Nm³ were not permitted any more in an increasing number of locations and the pressure grew, to lower these levels further to < 100 mg/Nm³.

This paper explains that the SNCR process is an attractive alternative to the SCR technology. Tests and practical operating experience both show that with the developments and improvements which have been made, the SCNR process even meets the latest requirements imposed by the regulators and represents now the state-of-the-art.

2. SNCR Plant Technology Complying with Standards of Future Legislation

Combustion plants where the first flue gas pass is free of heat exchangers are most suitable for the SNCR technology. The reason for this is that flue gas velocities are low enough for the flue gases to cool down in the combustion chamber to the point where the reaction for NO_x reduction is completed, before the flue gases enter into the heat exchangers. These operating conditions are typically found in plants with grate-fired boilers which burn waste, biomass, and coal, as well as in fluidized-bed boilers and smaller coal-fired boilers that are operated in heating plants, etc.

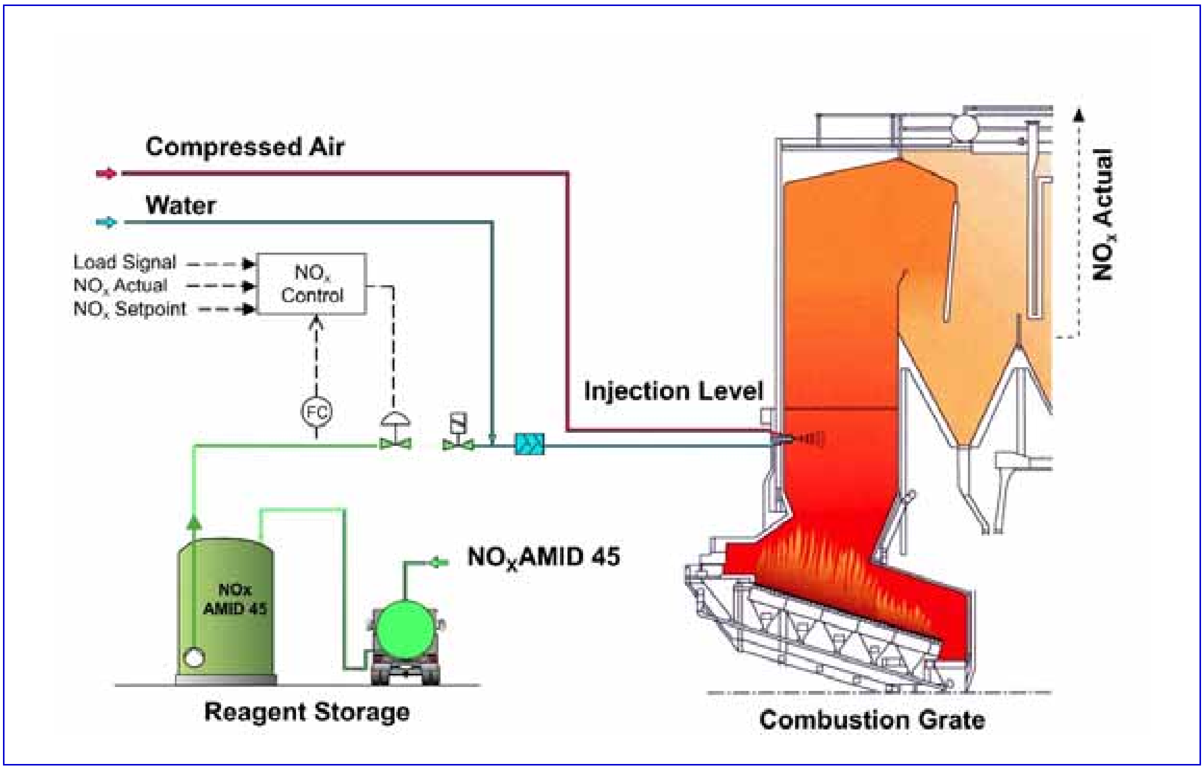


Figure 1: Process Flow Diagram of a simple SNCR plant

The simplified process flow diagram (**Figure 1**) shows the function and the scope of supply of an SNCR plant using urea solution as a reagent, typical for combustion plants. These plants are equipped with one or two injection levels which are individually activated depending on boiler load and/or flue gas temperatures.

This concept reliably allows meeting NO_x limits of 120 – 150 mg/Nm³ and NH_3 slip of < 30 mg/Nm³, if the injection lances are arranged in a way that they cover the relatively wide temperature window for injection. Variations in temperature and temperature imbalances, which result in low NO_x reduction in one place can be compensated by a higher NO_x reduction in another place. To prevent temperature variations and imbalances during operation from becoming too big, two injection levels have proven to be best. These two levels are activated depending on the average temperature at the boiler ceiling. Under favorable conditions, i. e. when homogenous fuels are used and boiler loads are constant, clean gas values of < 100 mg/Nm³ can be reached. However, imbalances in the temperatures and the flow of the flue gases can have a negative impact on NH_3 slip and the consumption of reagent.

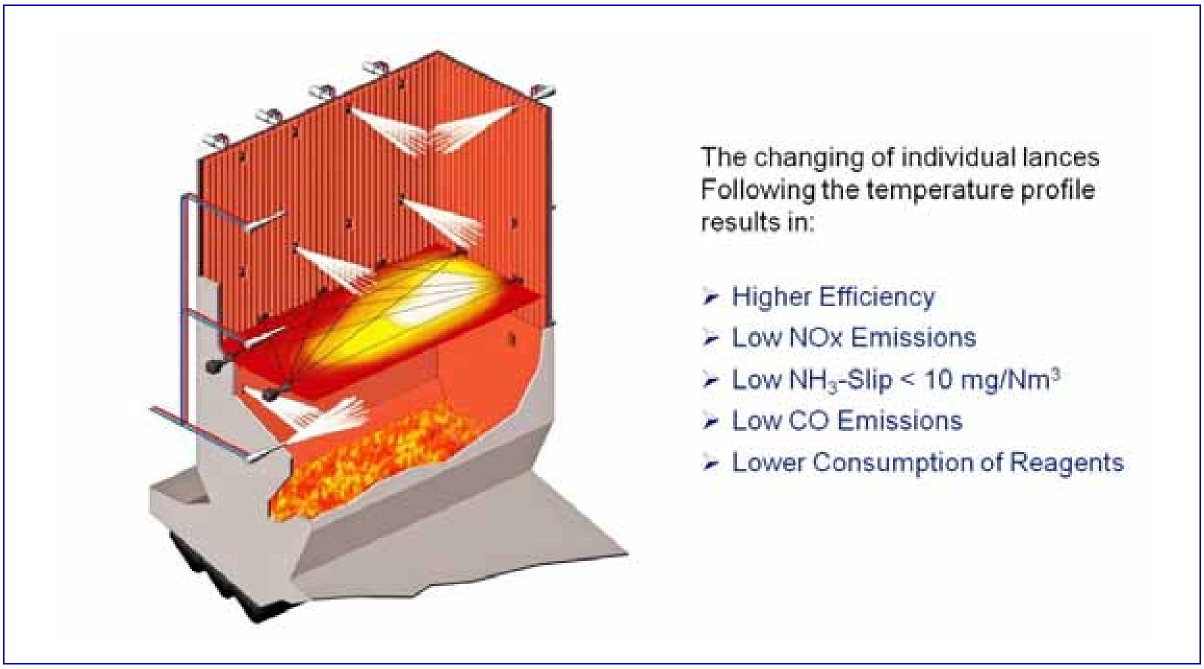


Figure 2: Temperature controlled changing of individual lances

In modern SNCR plants, the injection lances are activated individually depending on the flue gas temperatures at the injecting position. This ensures that the reagent is injected into the temperature window in an area which allows for optimum NO_x reduction, NH_3 slip and consumption of reagent.

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 measured. Even when there are sudden changes in the flue gas temperatures this method ensures that the reagent is injected into those areas that will achieve optimum results regarding NO_x reduction, NH_3 slip and consumption of reagent (**Figure 2**).

The results that were measured in continuous operation of several combustion plants show that NO_x clean gas values of < 100 mg/Nm³ and an NH_3 slip of < 10 mg/Nm³ are possible permanently and even noticeably better results can be achieved.

In Germany, the Netherlands and Sweden, SNCR plants commissioned to obtain NO_x levels < 100 mg/Nm³ are operated since several years and the required emission levels are reliably achieved in continuous operation. NO_x clean gas values and NH_3 slip are particularly low in those plants, which are equipped with an acoustic temperature measurement system (agam) plus three injection levels where each lance can be activated separately.

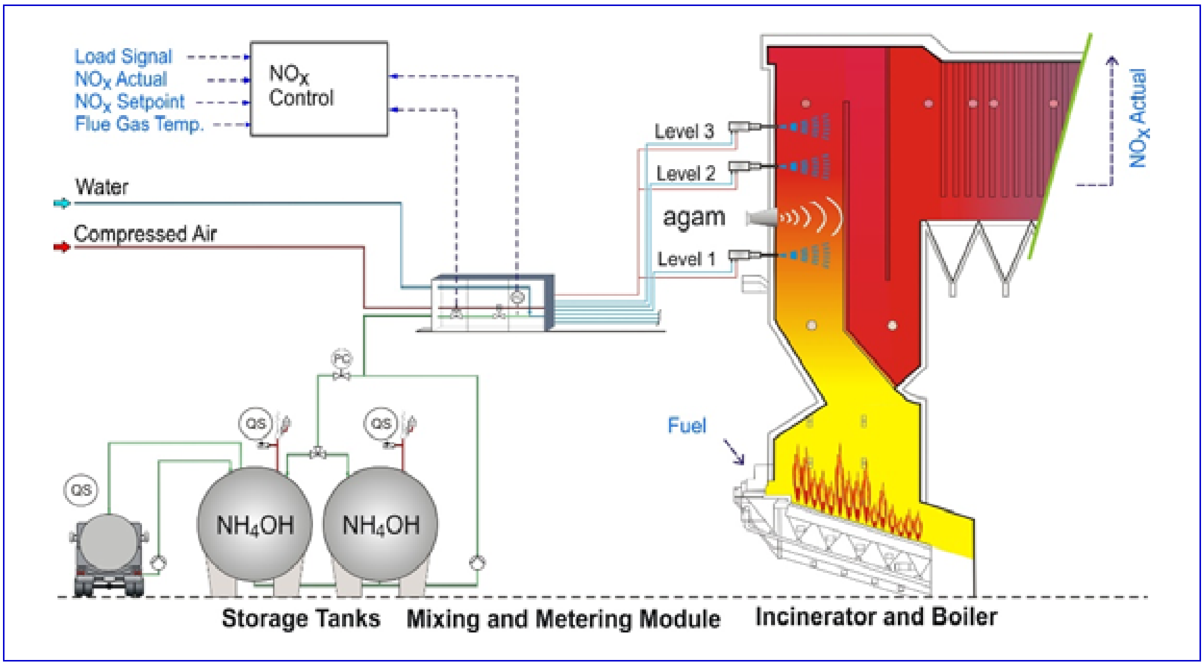


Figure 3: Process flow diagram - SNCR-plant with agam and three injection levels

One example is the waste-to-energy plant Wijster in the Netherlands where three SCR plants were decommissioned and replaced by SNCR technology. Due to the ambitious objectives (NO_x reduction from ca. 300 – 350 mg/Nm³ to < 50 mg/Nm³ and NH_3 slip < 10 mg/Nm³) the installation includes three injection levels with six injectors per incineration line (**Figure 3**).

Figure 4 shows the daily NO_x averages of the first SNCR plant. It is obvious that reaching the emission levels was no problem. During the first six months, the SNCR process achieved an annual NO_x average of < 50 mg/Nm³ dry at 11 % O_2. This result is at level with the results of the SCR plant, which reached annual NO_x averages of 45 mg/Nm³.

After retrofitting and putting into operation the other two lines, the guaranteed NO_x clean gas values could be met as well. It is remarkable that the NH_3 slip as a by-product of the flue gas cleaning was much lower than expected. In fact, it was so low that the originally foreseen NH_3 stripper for cleaning the waste water became obsolete.

Apart from the construction of new SNCR plants, many of the existing plants that were designed to comply with the required NO_x levels < 200 mg/Nm³ have to be retrofitted to meet the new NO_x emission standards of < 150 mg/Nm³.

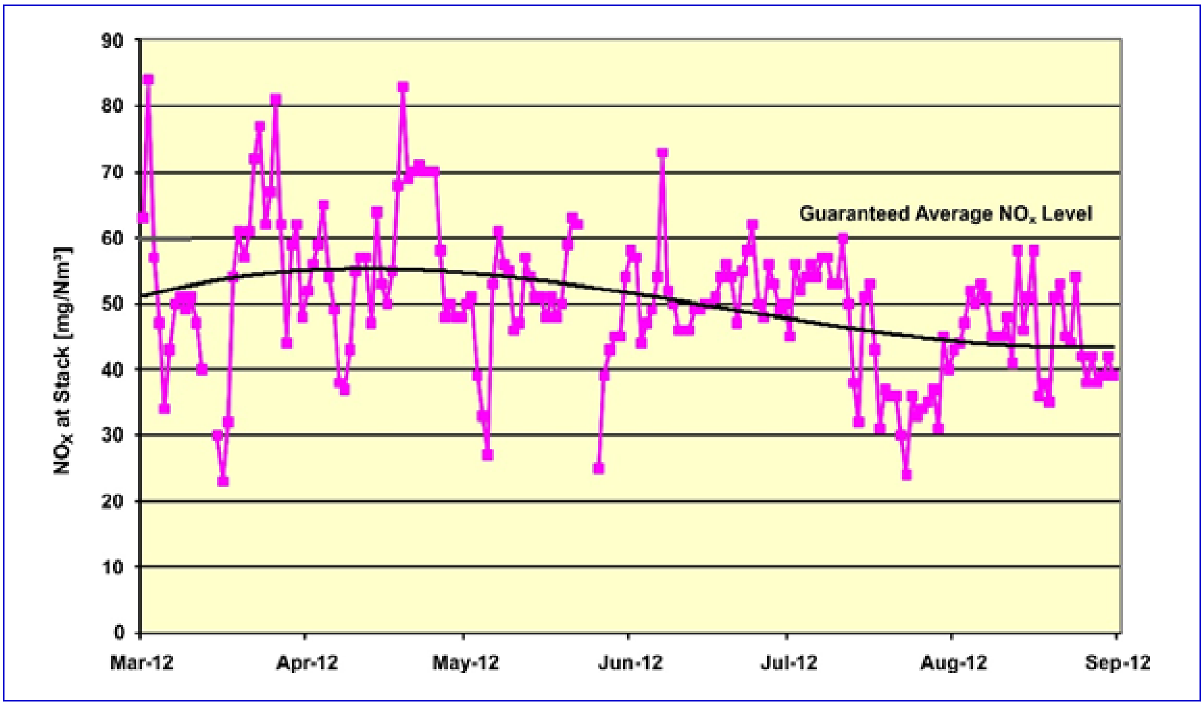


Figure 4: W-t-E Wijster – Long-term daily averages

3. Influences of Design and Operating Conditions on SNCR Performance

Contrary to common opinion, it is not enough to inject the reagent homogenously into the suited temperature window and to mix it thoroughly with the flue gases. Apart from the optimum temperature window, there are several other important parameters influencing the efficiency of the process. They are mainly influenced by:

- The boiler design
- The design of the combustion chamber
- The position of the heat exchangers
- The design and configuration of the burners
- The operating conditions in the boiler
- The type of fuel
- The reagent – urea solution or ammonia water

With regard to power boilers, the problems that have to be solved by suppliers of SNCR technology are more complex as compared to grate-fired boilers due to the size of these boilers . Especially at full load, temperatures tend to be too high in the areas that are free of built-in components. Consequently, at the furnace exit, the reagent will be burnt to NO_x. The temperatures favorable to NO_x reduction are often found between the heat exchangers, which are difficult to access or not accessible to injection at all. In addition to this, it is practically impossible to measure or determine the velocities and directions of the flue gases.

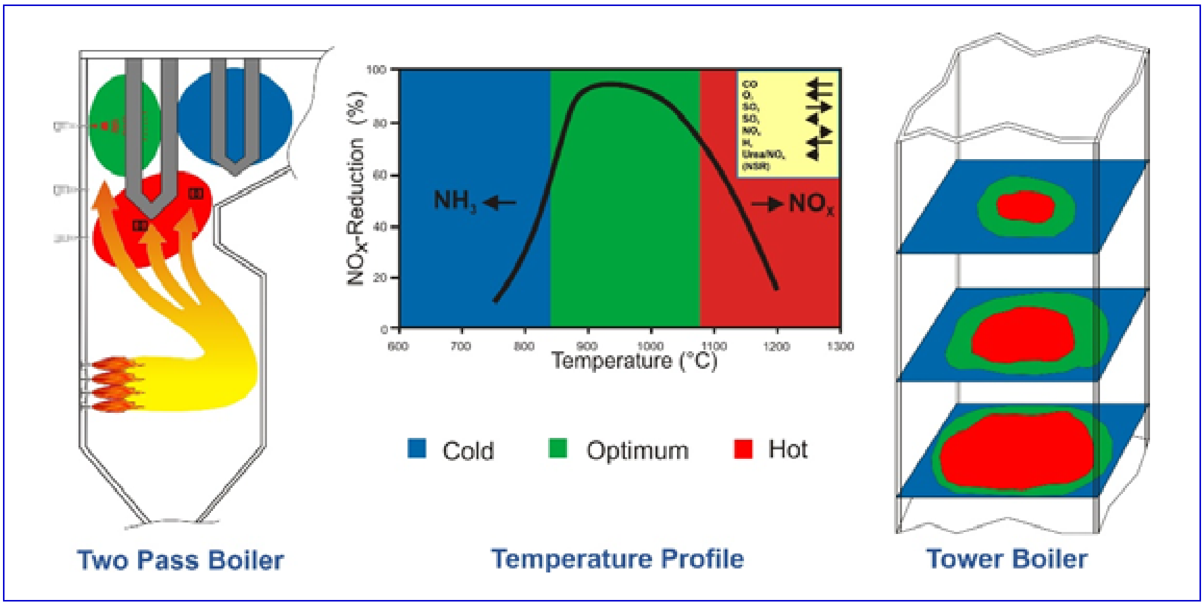


Figure 5: Temperature controlled NO_x reduction

In tower boilers the situation is different. The reagent can be injected in most applications from all four boiler walls. The hot flue gases stream upwards through the heat exchangers while the temperatures decrease from the center towards the boiler walls. The temperature profile in different cross-sections is such that there are three temperature areas of which only one is suitable for NO_x reduction at the different injection levels. Close to the boiler walls is the coldest temperature which produces higher ammonia slip. In the center the temperature is too hot over the whole load range so that the ammonia is burned to NO_x (**Figure 5**).

4. Solutions for an Improved SNCR Performance

In order to improve SNCR performance the following measures can be taken:

- Adjusting the SNCR plant to the existing boilers and operating conditions
- SNCR-friendly design of the boiler, retrofitting of the combustion plants, respectively reducing boiler load
- Cooling of the flue gases

When the flue gas temperatures are too high in areas that are free of built-in components, enough space has to be provided in the suitable temperature window for the injection and reaction of the reagent(s). This means that the heat exchangers have to be moved or stretched, which is usually a very costly undertaking. For new installations, the specific requirements of the SNCR technology should be considered during the design of the boiler, because then the additional cost can be kept to a minimum.

However, if retrofitting is not possible, and especially when several boilers are operated parallely, it might be a possible solution to limit the maximum load of the boilers so that the flue gas temperatures at the exit of the combustion chamber will stay within the effective temperature window.

4.1. Adjusting the SNCR plant to Existing Boilers and Operating Conditions

Initially, the aim should always be to adjust the SNCR plant to the operating conditions of the existing boilers and not vice versa.

If there is enough space for injecting the reagent and the residence time for the reaction is long enough, the usual temperature imbalances are no major issue. Since the introduction of the temperature controlled activation of individual lances, it is possible to guarantee that the reaction takes place in the optimum temperature range across the whole cross-section of the furnace.

4.2. Cooling of the Flue Gases with Additional Water

The potential for further developments is highest in larger combustion plants, where the flue gas temperatures are too hot for the SNCR technology in those areas that are accessible to injection. The objective is to provide the necessary operating conditions, i. e. to cool down the flue gases so that NO_x reduction is possible in any load scenario.

In this regard, a possible measure would be to increase the quantity of dilution water. However, this has the following disadvantages and is therefore not recommended in most applications:

- Varying quantities of water change the droplet spectrum and consequently the size of the droplets as well as their penetration depth.
- The concentration of the water-reagent-mixture is also changed so that the area where the reduction takes place is shifted.

A continuous operation of the boiler with an increased amount of water is acceptable only as an exception, because vaporizing the water consumes a lot of energy and affects the efficiency of the combustion plant. (**Figure 6**)

Controlling the quantity of water depending on boiler load respectively temperature is a standard procedure and has been practiced since many years in oil-fired fire tube boilers. The previously mentioned disadvantages do not apply to these boilers, as the reagent is injected against the direction of the flue gas flow, and the penetration depth is adjusted deliberately in order to follow the changes of the flue gas temperatures.

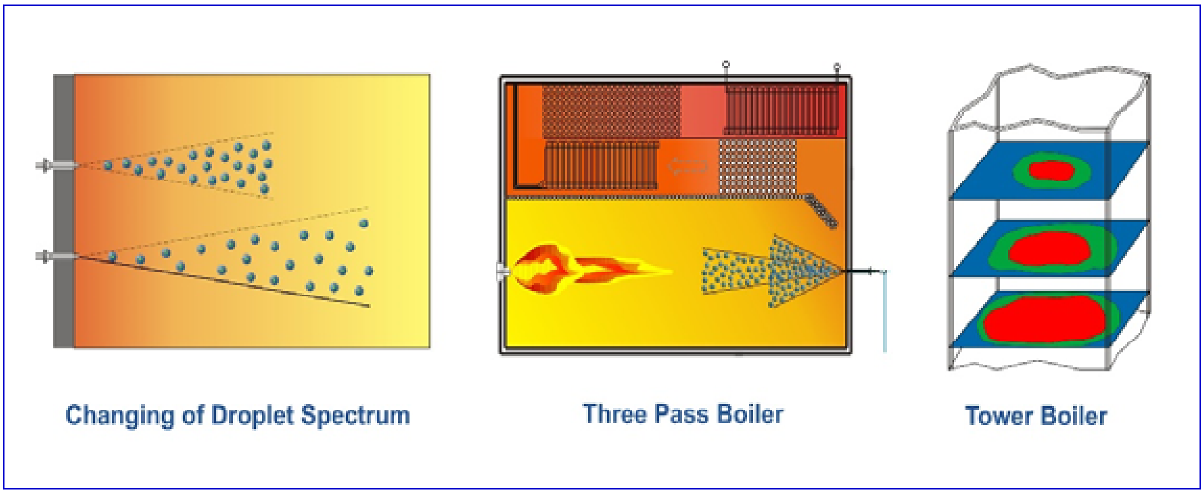


Figure 6: Flue gas cooling by inreasing the quantity of cooling water

In larger boilers where the reagent is practically always injected rectangularly to the flue gas flow, the installation of an additional injection level which can be operated with cooling water alone, when needed, has proven successful in continuous operation.

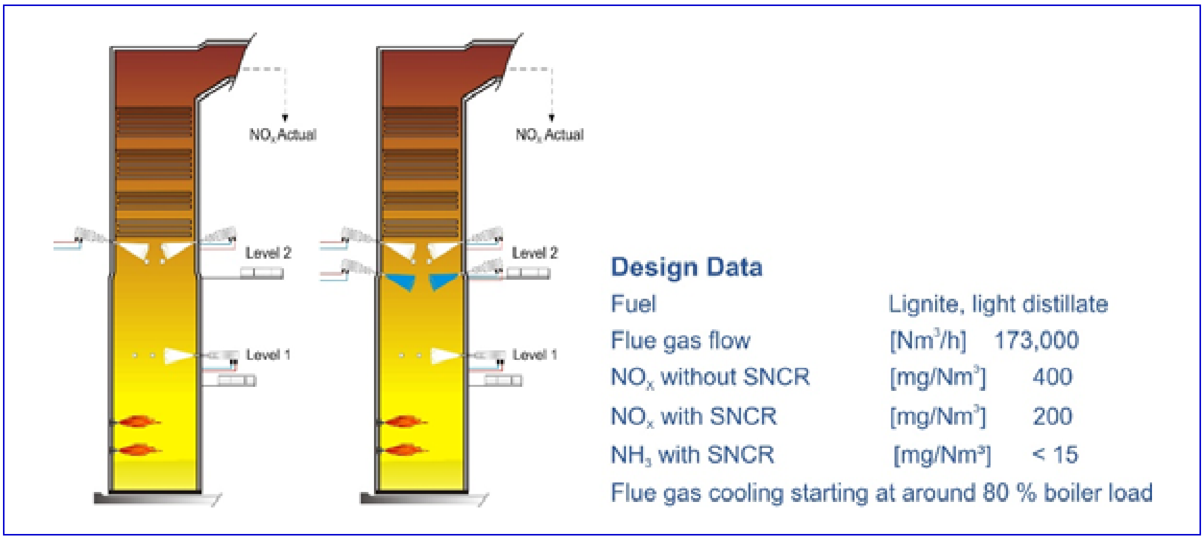


Figure 7: Coal-fired boiler with and without flue gas cooling

With this concept cooling water is only applied when temperatures are too high. At lower loads, respectively temperatures, the water is switched off. The droplet spectrum is not changed, but the disadvantage is that temperature imbalances can lead to a higher NH_3 slip, because the cooling also takes place in areas where cooling is not needed.

Preferably, this method should be applied in combustion plants that are not constantly operated in temperature ranges which require an additional cooling of the flue gases or in plants with homogenous temperature profiles. By switching on or off the cooling water, it is possible in many cases to do without an additional injection level in many cases.

The plant shown in **Figure 7** which is rarely operating at full load does not need a catalyst by applying this method. With the addition of cooling water alone, a reduction of the NO_x clean gas value < 180 mg/Nm³ is achieved. The raw gas value (NO_x without SNCR) is ca. 400 mg/Nm³.

5. Most Recent Developments of NO_x Reduction with SNCR

5.1. TWIN-NO_x® – Combination of Urea Solution and Ammonia Water

In search of improvements in SNCR technology, trials were performed at the plant MKV Fenne which compared the reagents urea solution and ammonia water under identical operating conditions (**Figure 8**).

The results of these trials demonstrated that the NO_x clean gas concentration decreased by approximately 50 mg/Nm³ immediately after urea solution had been injected and the consumption of reagents was lowered significantly. It became obvious at first glance that at full load, urea solution produced better results in this type of boiler than can be achieved with ammonia water.

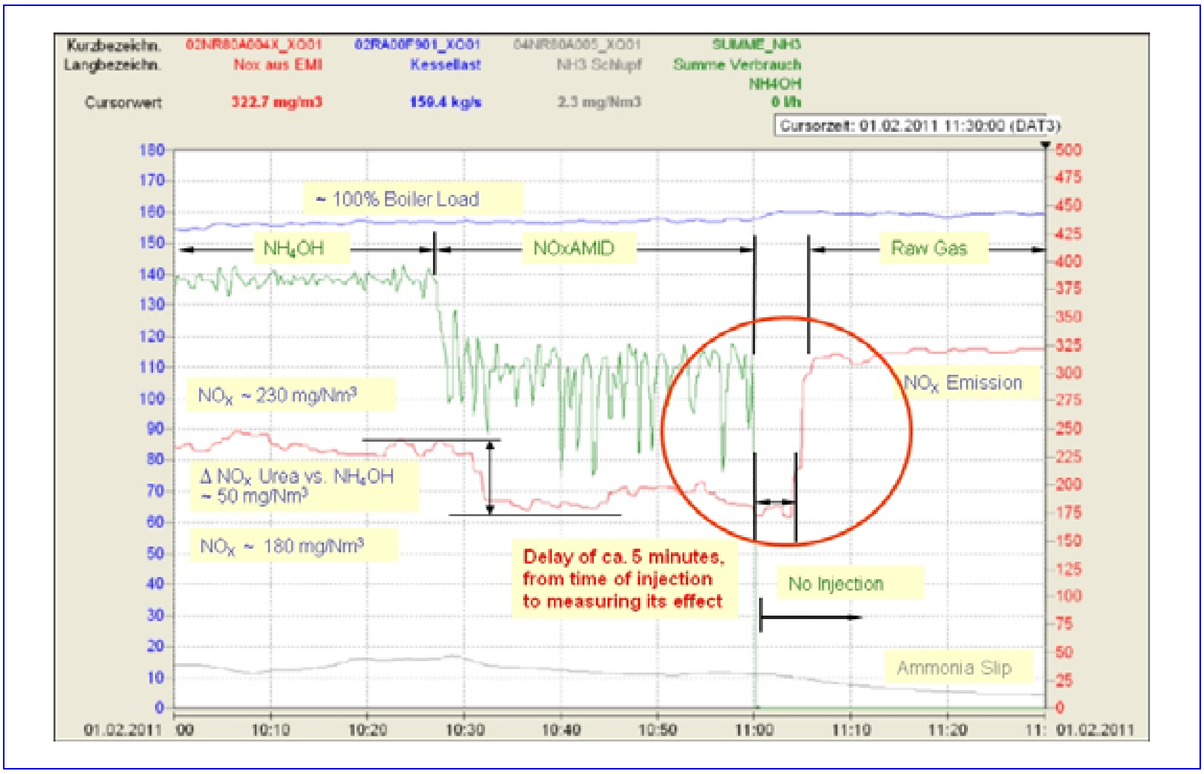


Figure 8: Injection of ammonia water and urea solution

In principle, these tests also confirmed that the reagent based on urea solution (NOxAMID) which has a low volatility is released at the end of the droplets' trajectory, whereas reagents of high volatility (NH_3) are released near the nozzles and the boiler walls (**Figure 9**).

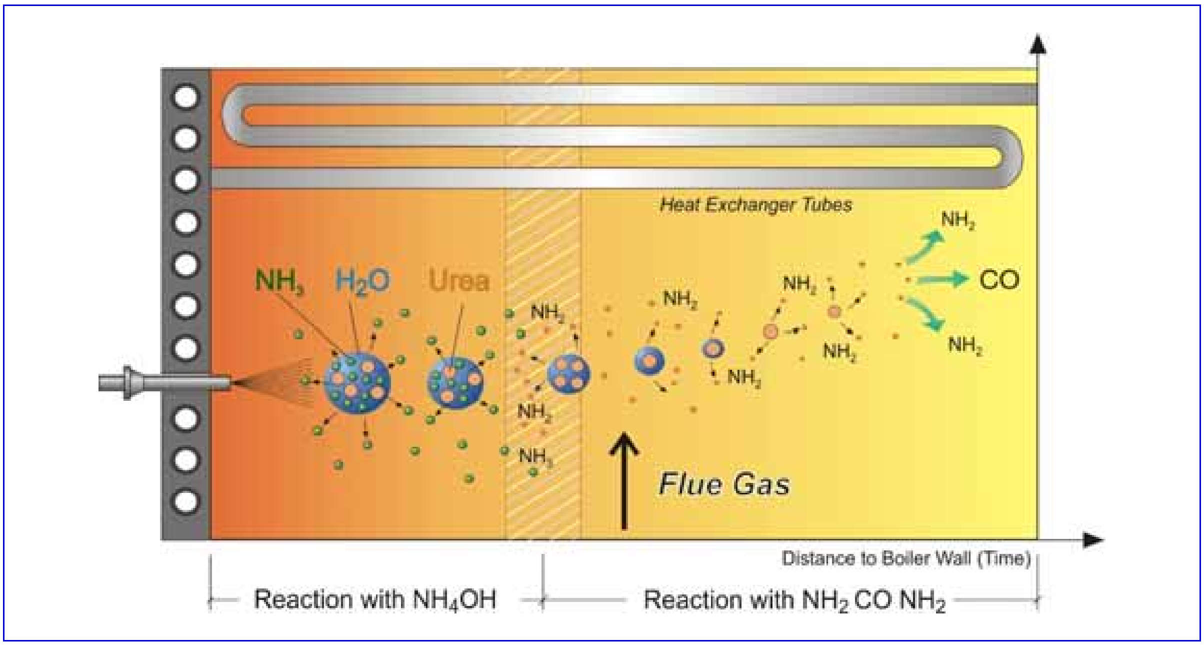


Figure 9: TWIN-NO$_x$® – Mixing of ammonia water and urea solution

Additional tests showed that there is further potential for improvements when both reagents are used and applied depending on the operating conditions.

The positive aspects of both reagents are most effective, when they are injected simultaneously and the mixing ratio is adapted according to the actual operating conditions.

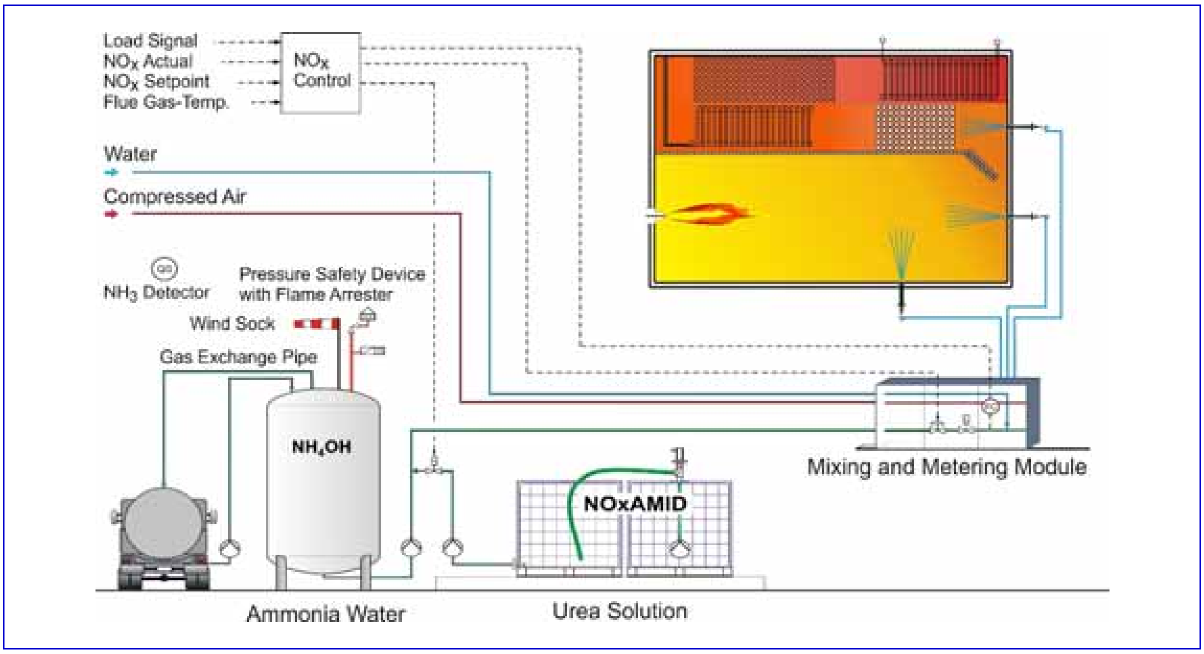


Figure 10: TWIN-NO$_x$® – Process flow diagram for a boiler fired with light distillate

This process, which has been developed by analyzing the experiences made, has been registered as a trademark under the name of TWIN-NO$_x$®.

The process flow diagram of the first commercial use of the TWIN-NO_x® technology in 2010 is shown in **Figure 10**. This plant was originally designed to be operated with ammonia water. When realizing that the guaranteed NO_x clean gas value of < 180 mg/Nm³ could not be achieved at full load because the temperatures in the furnace were too hot, the boilers were retrofitted for the additional operation with urea solution.

In a coal-fired boiler (**Figure 11**) an SNCR plant for operation with ammonia water was installed in 2009. The guaranteed NO_x level of < 300 mg/Nm³ was reached without exception, although operating conditions like boiler load, burners in operation and cycles of the soot blowers changed considerably, so that the temperature distribution and flue gas flow were unpredictable.

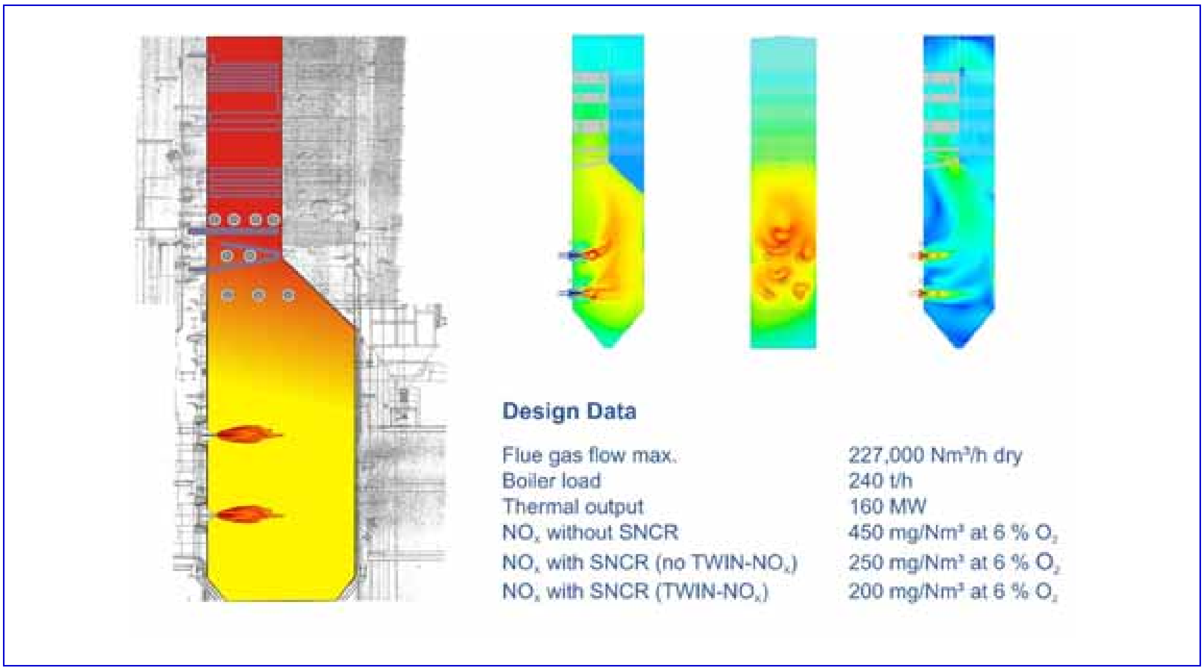


Figure 11: TWIN-NO_x®: Temperature Profile and Flue Gas Flow

In order to be able to consider the specific conditions of the boiler for the design of the injection concept, temperature measurements with suction pyrometers were performed in 2014. Furthermore, TWIN-NO_x® was tested under difficult operating conditions. These tests provided reliable information that the SNCR technology could be improved to guarantee NO_x levels of < 200 mg/Nm³ in the clean gas and how this objective could be achieved.

Since the results of these tests were positive even under critical conditions, the SNCR plant was retrofitted with a commercial TWIN-NO_x plant to meet NO_x emissions levels < 200 mg/Nm³.

5.2. Selective Cooling of Flue Gases

A logical development of the method described above is called "Selective Cooling", which also requires an additional injection level for cooling water beneath the upper injection level. The difference is that Selective Cooling considers temperature imbalances in a way that cooling water is injected only in those areas which are too hot (**Figure 12**). Depending on the temperature profile individual lances or a group of lances are activated.

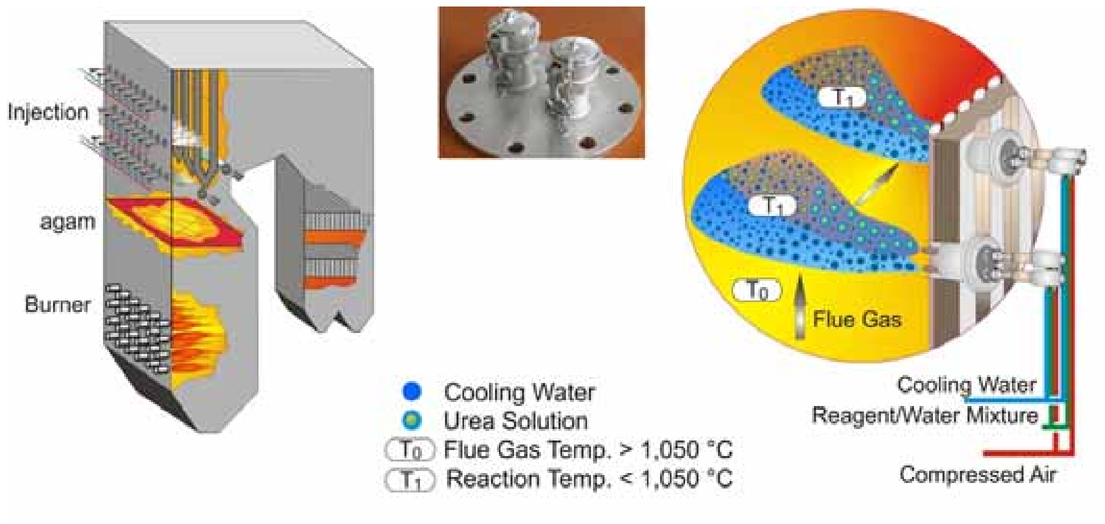
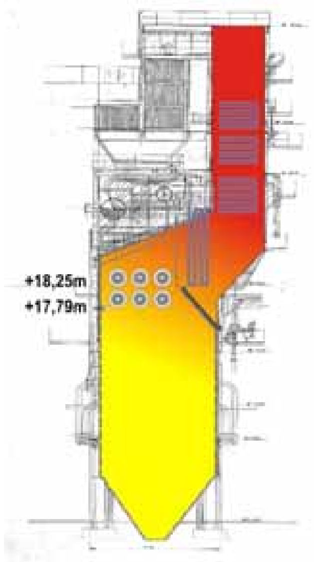


Figure 12: Selective Flue Gas Cooling for coal-fired boilers



Design Data

Flue gas flow max.	100.000 Nm³/h dry
Boiler load	85 t/h
NO_x without SNCR	400 mg/Nm³ at 6 % O_2
NO_x with SNCR	250 mg/Nm³ at 6 % O_2
NO_x with SNCR (with additional water)	160 mg/Nm³ at 6 % O_2

Figure 13: Selective Cooling - Retrofitting of an SNCR plant operated with urea solution

Figure 13 shows the results of the Selective Cooling in a coal-fired boiler in the Czech Republic. With additional cooling water alone, the performance of the SNCR could be improved by additional 120 mg/Nm³ NO_x reduction to a level of 160 mg/Nm³ (**Figure 14**).

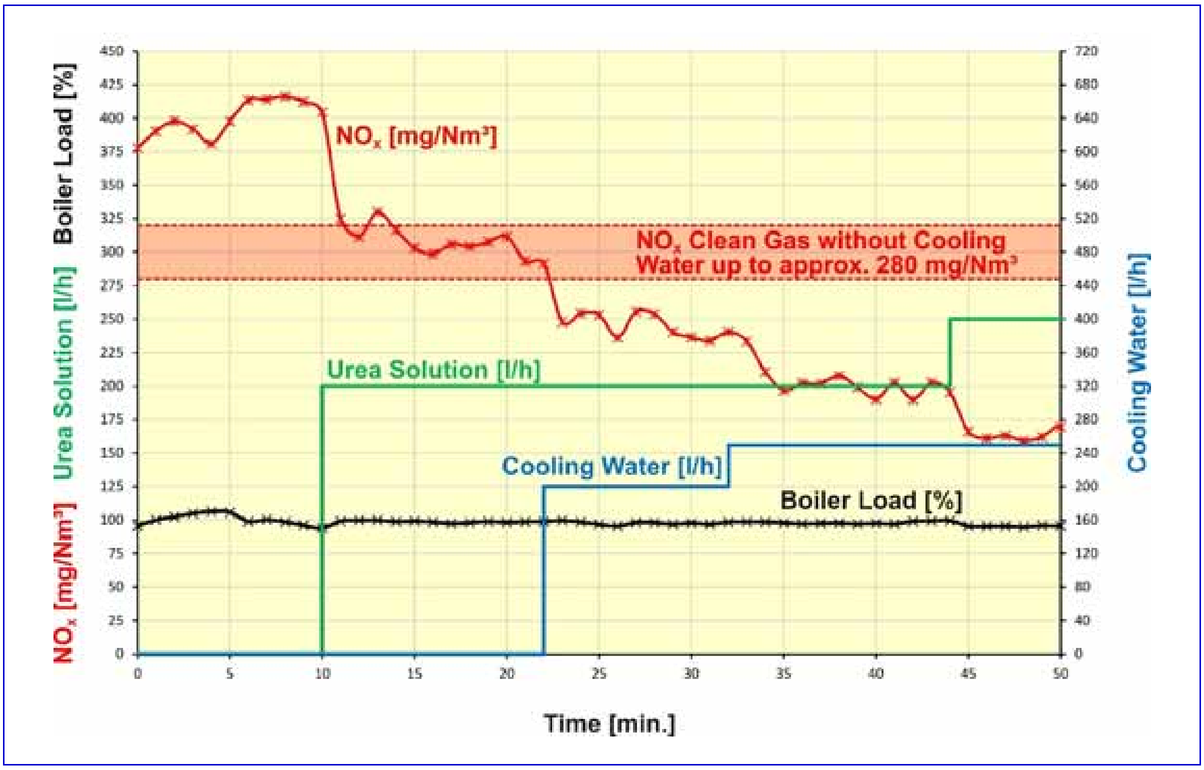


Figure 14: Increase of NO_x reduction by adding cooling water for flue gas cooling

5.3. Adaptive Flue Gas Cooling

Injecting of water offers the great benefit that extensive and costly modifications of the boiler can be avoided when the flue gases are cooled down before entering the heat exchangers. The major disadvantage, however, is that depending on the operating hours at high boiler loads in which water cooling is necessary, the efficiency of the boiler is affected because of the energy needed to evaporate the water in the flue gas. "Selective Cooling is already a big step forward to cool down the flue gases and save energy at the same time.

However, a better solution is to control the amount of water more precisely in order to achieve a further optimization of the conditions for the SNCR process.

For this reason, a temperature measurement system which generates a temperature profile has to be installed above the upper injection level of the cross-section of the furnace (**Figure 15**).

The temperatures will be measured online constantly and average flue gas temperatures will be determined in defined sections

- Without injection of reagent
- With injection of reagent only
- With injection of reagent and cooling water simultaneously.

Above the lowest injection level, another temperature measurement system has to be installed for measuring the flue gas temperatures

- Without injection of reagent
- With injection of reagent.

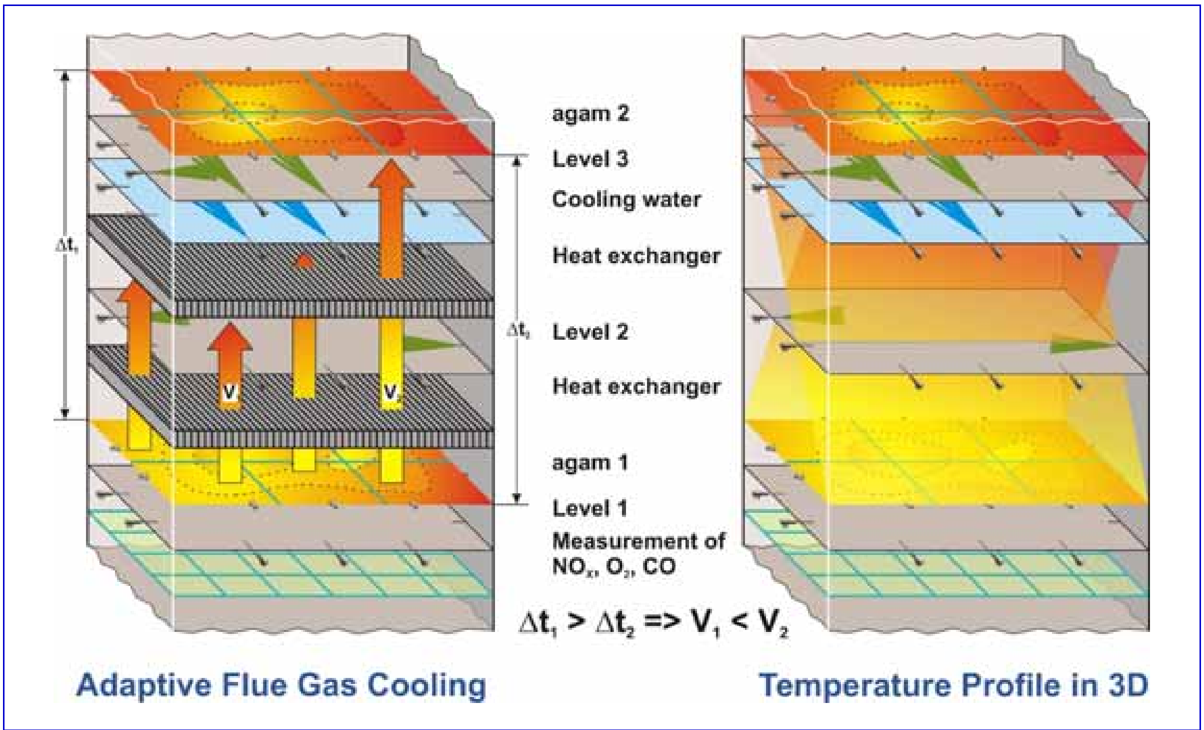


Figure 15: Adaptive cooling and extrapolation of flue gas velocities

At the lowest level, injection of cooling water is generally not needed, since the injectors will be switched to higher levels as the flue gas temperatures increase with the load.

With the described concept the temperatures and the influence of the injected liquids, as reagent-water-mixture and cooling water, can be measured. Based on this, the temperatures between the two levels can be calculated so that the flow of cooling water can be adapted with regard to efficient NO_x reduction and low ammonia slip. Furthermore, the activation of the lances for reagent can be defined more precisely.

It is often neglected that apart from the flue gas temperatures, the flue gas velocities at different locations where the reagents are injected, are of equal importance for the efficiency of the SNCR process. Since the NO_x to be reduced is the product of ***NO_x concentration * velocity***, the probability is high, that in some areas where the flue gas velocities are low, too much reagent is injected in areas with similar NO_x concentration causing higher ammonia slip since the reagents do not find enough partners for the chemical reaction. To avoid this, the flow of reagent should be reduced or stopped.

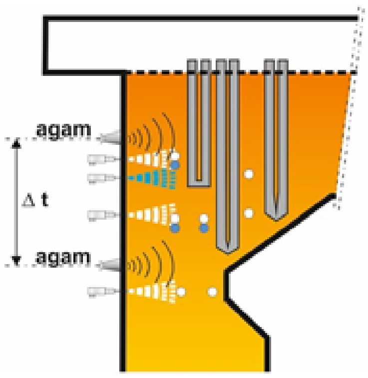
With this arrangement of the temperature measurement systems, the temperatures in different levels and sectors can be compared and the temperature gradient between the levels can be defined more correctly than with traditional methods.

Since hot flue gases have a higher natural draught and slower flue gases are cooled down more at the boiler walls and heat exchangers, higher temperature differences indicate a slower flue gas velocity compared to areas with smaller temperature differences.

This information is the basis to control, respectively adjust the flow of reagent to the corre-sponding injectors or groups of injectors with the objective to optimize the NO_x reduction and to minimize the ammonia slip.

If measuring equipment were used which provides data of other components like NO_x, CO, O_2, etc. in addition to the temperatures, these data could be incorporated into the control of the SNCR as well as to further optimize the distribution of the reagent across the furnace for better performance of the SNCR.

The temperature profiles on two levels offer further opportunities and improvement as shown in **Figure 16**.



Acoustic Gas Temperature Measurement System (agam) provides
- Flue gas temperature profiles without SNCR
- Flue gas temperature profiles with SNCR
- Flue gas temperature profiles with SNCR and selective cooling
- Temperature gradient between two injection levels
- Effect on deposits of fly ash on heat exchangers

Temperature Information is used for
- Injecting reagent in areas with optimum temperatures
- Cooling flue gas in areas which are too hot for SNCR
- Controlling process water to vary penetration and spraying pattern of reagent
- Controlling of cooling water
- Controlling of ammonia slip
- Flue Gas velocities can be derived from temperature gradients

Results
- Higher efficiency (NO_x reduction)
- Low ammonia slip
- Less water consumption
- Low consumption of reagent

Figure 16: Improvement of SNCR control using temperature profiles

5.4. Combining Measures for Optimizing SNCR and Combustion Modifications

The NO_x emissions after the furnace depend on both the performance of the combustion and the SNCR.

The results of SNCR can therefore only be as effective as the combustion permits. The objective of primary measures should be to provide optimum conditions for SNCR. This means that the formation of NO_x should already be avoided as much as possible during the combustion process, and the flue gas flow and temperature profiles should be as homogenous as possible. Combining this with an SNCR plant, NO_x clean gas values will be achieved that would not be possible when applying one of these measures alone.

Both measures have advantages and disadvantages. Therefore, it is essential for long-term commercial use to find a compromise between the technical feasibility and the commercial impact as well as the effects on the operating conditions. A lack of oxygen for instance can cause a wear-off of material in the boiler tubes. In the SNCR process, ammonium salts can be formed when NH_3 slip is too high, which may cause trouble further downstream, e. g. the precipitation of ammonia salts on the heat exchangers, a high load of NH_3 in the fly-ash as well as the sewage water and the by-products of the flue gas cleaning.

6. SNCR Application in Coal-Fired Boilers in Poland

The results of operating experiences with coal-fired boilers in Poland prove that some differences in the design of the boiler and the configuration of the burners have a major influence on the flue gas flow and temperature distribution and consequently on the efficiency of the SNCR process.

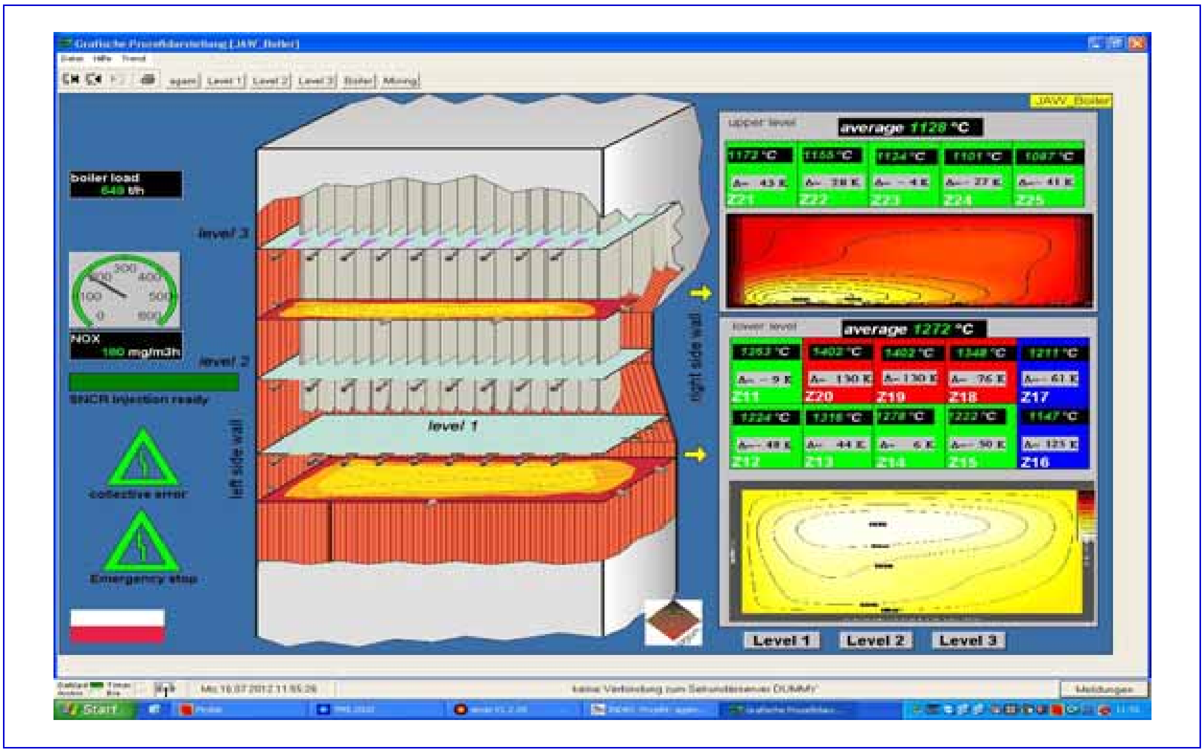


Figure 17: Coal-fired boiler – Display of operating data and temperatures in two levels

By far the best results could be achieved in boilers with corner-firing, like in the power plant in Polaniec, Poland, where during trials reduction rates of up to 58 % were achieved. In corner-fired boilers the flue gases are circulated, which has several positive effects on the SNCR process as opposed to front-fired boilers or boilers with boxer-firing. In a corner-fired boiler, the flue gases have a lower temperature when entering the heat exchangers, the temperature imbalances are less extreme and the formation of streams is reduced.

With computer simulations it is possible to provide a rather detailed description of all parameters relevant to the SNCR process, like temperature profile, direction and velocities of the flue gases, distribution of components (NO_x, CO, O_2 etc.) in the flue gas. If the resulting potential were used more consequently, this would offer further opportunities.

In another power plant location in Poland, Jaworzno, six coal-fired boilers of the same type (OP 650) are operated with front-firing. After exchanging the burners and retrofitting the supply of combustion air, a commercial SNCR plant was installed in one of the boilers. First operating experiences with other boilers and the results of the previous tests with similar applications were taken into consideration as much as possible.

The design includes three injection levels with lances for the injection of urea solution which can be activated individually, enabling the plant to react to changes of load and temperature. Due to the extreme temperature imbalances of up to 200 K, which had been measured at the beginning of the design phase, an acoustic temperature measurement system (agam) with two levels was installed (**Figure 17**). The second agam level allows for a more precise temperature measurement near the injection lances and is utilized to determine the temperature gradient between the two agam levels.

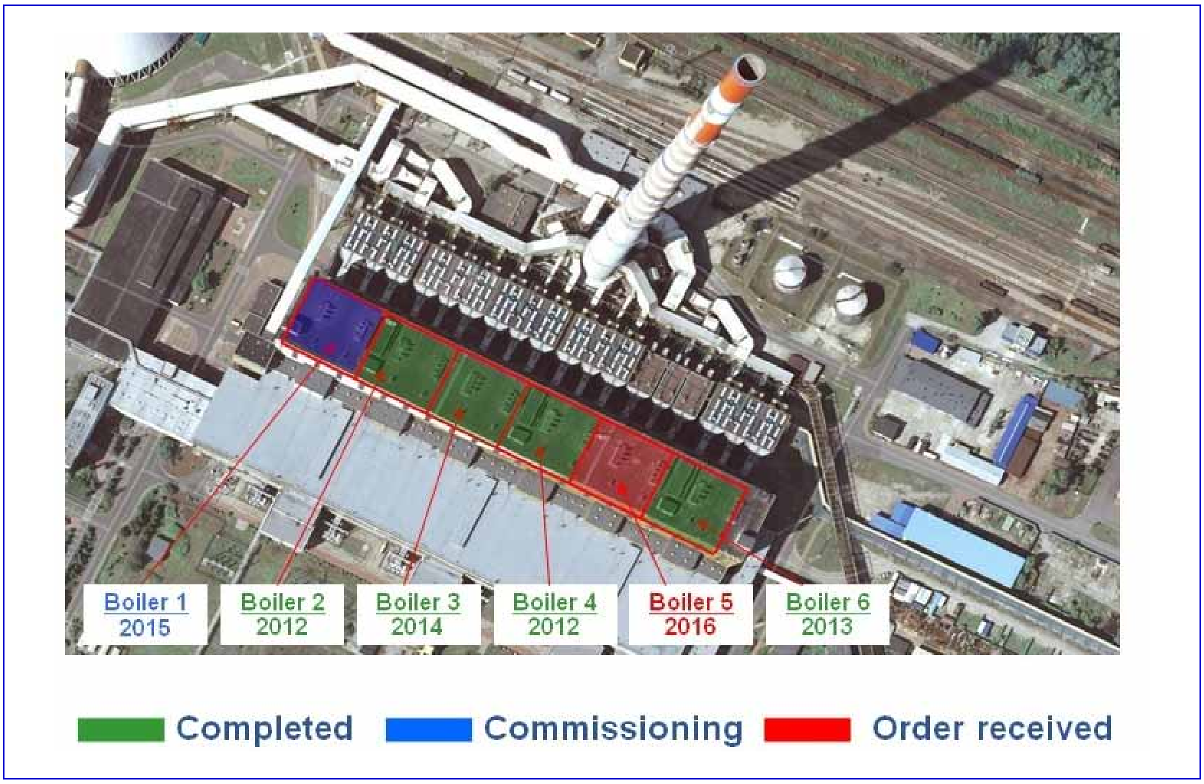


Figure 18: SNCR plants at the power-plant in Jaworzno III, Polen

The SNCR plant was commissioned in March 2012 and handed over to the customer shortly after. Since then the plant has been in continuous operation and runs smoothly and to the full satisfaction of the customer. A second boiler was handed over in September 2012 and a third one in November 2013. The fourth boiler was handed over at the end of 2014, one is being commissioned now and the last one has been ordered in the first quarter of 2015 (**Figure 18**).

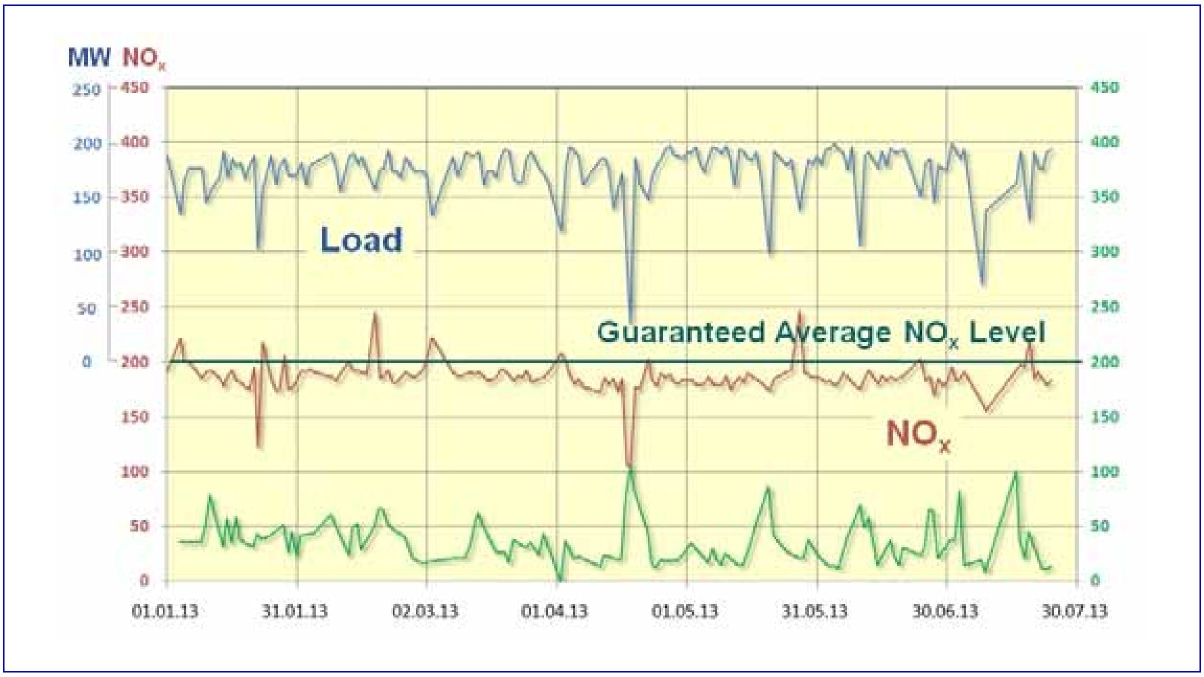


Figure 19: Jaworzno III – Long Term Performance Data

After commissioning of the first boiler, the flue gas temperatures were found to be higher at full load than expected. Therefore, the upper injection level in the second boiler was moved up a little higher, to a place where the temperatures are colder. Although the guaranteed NO_x levels in the first boiler had been met, an optimizing process was started in close cooperation with the customer, where the results were analyzed, improvements developed and then introduced step by step. There were also considerable peaks and imbalances in the NO_x raw gas concentration. In order to optimize the SNCR plant further, three NO_x control valves were installed with the result of lowering ammonia slip in the flue gas and in the ash and reducing the consumption of ammonia water.

Combined with the primary measures the guaranteed NO_x levels of < 200 mg/Nm³ are reached at all operating conditions (**Figure 19**) The average NH_3 load of the fly-ash measured in the period from January 1, 2013 to July 30, 2013 was 37 mg/Nm³.

In April 2015, M&S was awarded with the contract to install four SNCR plants in the power plant in Rybnik. The boilers are of the same type as in Jaworzno, OP 650, with a capacity of 225 MW_{el}. However, some design features are different as shown in **Figure 20** and have a considerable impact on the performance of SNCR as can be seen in **Table 1**.

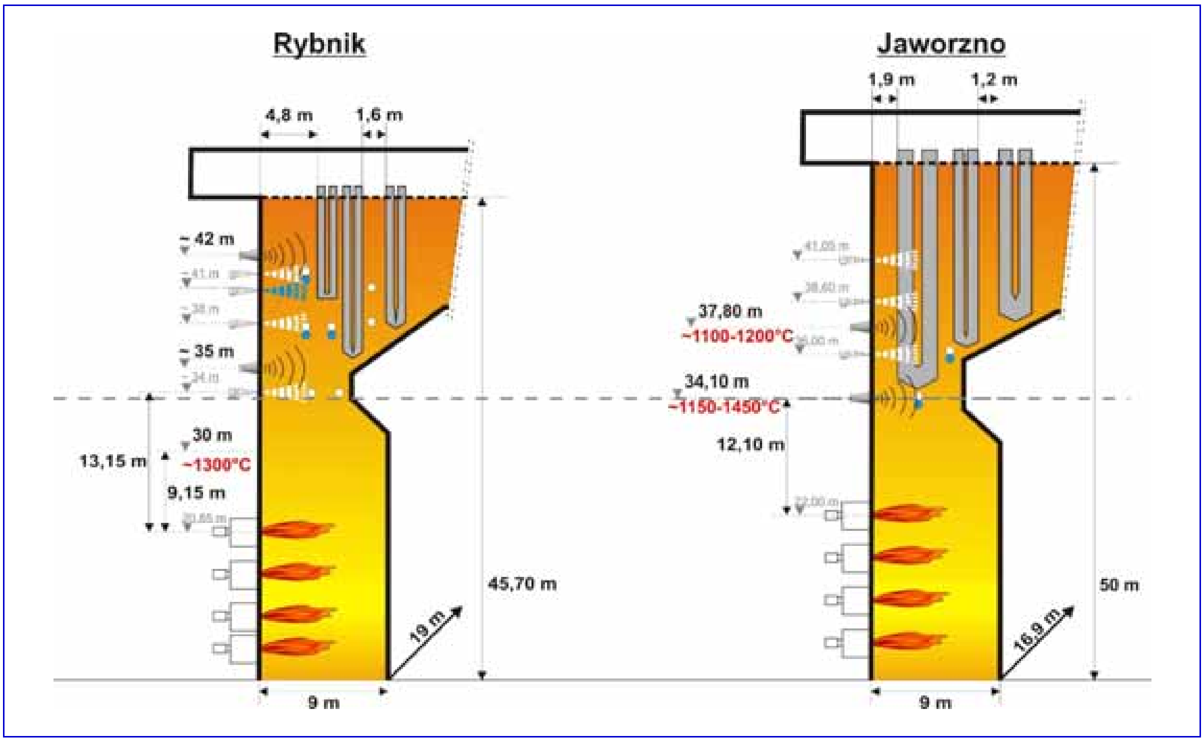


Figure 20: SNCR application for coal-fired boilers OP 650 (225MW$_{el}$)

Design Data	Unit	Rybnik	Jaworzno
Boiler capacity	t/h	650	650
NO_X baseline	mg/Nm³	300-340	250-280
NO_X emission limits	mg/Nm³	< 190	< 190
NH_3 slip	mg/Nm³	< 3,5	< 5
Ammonia in fly ash	mg/kg	< 100	~ 50
agam level	m	30	34.1
Average temperature of flue gas	°C	1,300	1,350
Furnace cross section	m m²	19 x 9 171	16.9 x 9 152.1
Boiler height	m	45.7	50
Boiler front wall to platen superheaters	m	4.8	1.9

Table 1: Design data of two boilers OP650 in Poland

Figure 21 shows the mixing and metering modules and injectors for reagent which are installed in the power plant Jaworzno.

Figure 21: Jaworzno III - Mixing and metering modules and injection lances

7. Summary and Outlook

In smaller combustion plants, e. g. those which burn waste or biomass, the SNCR process represents an industry-standard and state-of-the-art method. In the meantime, operating experiences in large combustion plants with a capacity of > 200 MW_{el} have shown over the past few years that SNCR can safely and reliably achieve the NO_x level < 200 mg/Nm³ which will be enforced by EU legislation in 2016. Different injection concepts which can be used separately or in combination are seen in **Figure 22**.

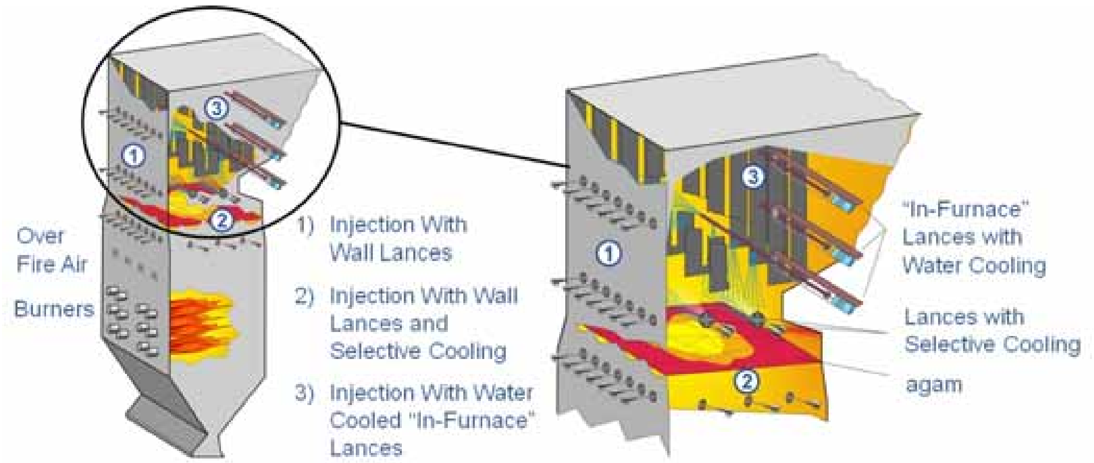


Figure 22: Injection concepts and configuration of injection lances

The initial results of the newer technologies, like the changing of individual lances, the TWIN-NO_x® process, the "Selective Cooling" and the combination of these methods with primary measures indicate that there is further potential for developments. The next step will be plants with boiler capacities from 300 to 500 MW_{el}.

8. Literature

von der Heide, Bernd: “SNCR-process – Best Available Technology for NO_x Reduction in Waste to Energy Plants”, Power-Gen Europe, Milan, June 3 – 5, 2008

von der Heide, Bernd: “Advanced SNCR Technology for Power Plants”, Power-Gen International, Las Vegas, December 13 – 15, 2011

von der Heide, Bernd: “SNCR-Verfahren der Zukunft für Großfeuerungsanlagen – Konzepte, Erfahrungen, TWIN-NO_x®-Verfahren“ in: Michael Beckmann, Antonio Hurgado (Hrsg.): Kraftwerkstechnik – Sichere und nachhaltige Energieversorgung – Band 4. Neuruppin: TK Verlag Karl Thomé-Kosmiensky, 2012, S. 623 – 635

Moorman F., von der Heide B., Stubenhöfer C.: “Replacement of an SCR DENOX system by a highly efficient SNCR in a waste-to-energy plant in the Netherlands“ in VGB POWERTECH Volume 93 – Issue 12/2013, page 76 - 82