Complying with New NO$_x$ Emission Standards The Challenges of SNCR Technology and its Solutions

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1. Introduction

The NO$_x$ reduction rates which have been achieved in recent years using non-catalytic technologies (SNCR) have proved to be reliable even in applications which were believed to work only with the more costly SCR process in the past. In the meantime, SNCR has advanced to be the Best Available Technology (BAT) in grate-fired combustion plants.

In power plants, NO_x emissions can be lowered to 200 – 250 mg/Nm³ in the flue gases by applying primary measures alone. An additional reduction below the actual emission level of 200 mg/Nm³ is more and more often realized by using SNCR technology. Due to their size and operating conditions power plant boilers have more complex requirements than Waste-to-Energy plants. Therefore, further steps are needed to catch up with the advances that the SCR process still has over SNCR. This paper describes the technological developments of the recent past.

2. Post-Combustion NO_x Reduction Technologies

Two Post-combustion NO_x control technologies which are widely used are the selective catalytic reduction (SCR) process and the selective non-catalytic reduction (SNCR) process.

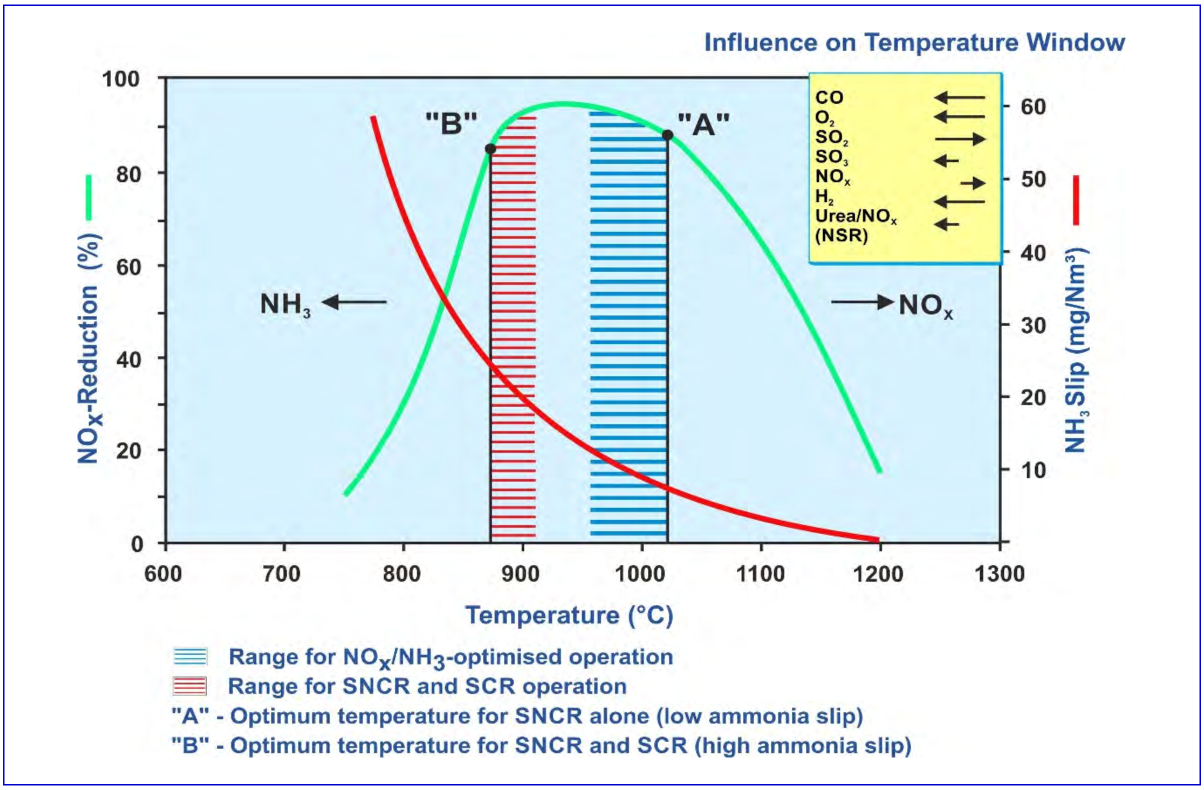


Figure 1: NO_x reduction as a function of temperature

SNCR and SCR have in common that both reduce NO_x to N_2 and H_2O with ammonia or urea based reagents. The major difference of the two systems is that the reaction without catalyst takes place in a temperature range between 900 °C and 1,050 °C (**Figure 1**) and with catalyst between 160 °C and 350 °C.

3. Retrofitting of Existing Combustion Plants with SNCR

In the **S**elective **N**on-**C**atalytic **R**eduction (SNCR) process of nitrogen oxides, reagents in aqueous solution (ammonia water, urea) or in gaseous form (ammonia) are injected into hot flue gases. Following the overall post-combustion reactions for

Urea $NH_2CONH_2 + 2\ NO + \frac{1}{2}\ O_2 \rightarrow 2\ N_2 + CO_2 + 2\ H_2O$

or for

Ammonia $4\ NH_3 + 4\ NO + O_2 \rightarrow 4\ N_2 + 6\ H_2O$

molecular nitrogen (N_2), water vapor (H_2O) and with urea carbon dioxide (CO_2) are formed. Basically, both urea solution and ammonia water can be used for the NO_x reduction in combustion plants. Depending on the application, both reagents have specific advantages and disadvantages. For an optimum NO_x reduction with a minimum NH_3 slip it is "only" necessary to evenly distribute and thoroughly mix the reagent in the flue gases within the appropriate temperature window in which an NO_x reduction is possible. The optimum temperature range to achieve a high NO_x reduction combined with a minimum consumption of reagent and a low ammonia slip is rather narrow and depends to a great extent on the flue gas composition (**Figure 1**).

For coal-fired boilers the optimum temperature lies between about 960 and 1,020 °C Above this temperature range ammonia is oxidized to an increasing extent, i.e. nitrogen oxides are formed.

At lower temperatures the reaction rate is slowed down, causing an ammonia slip which may result in the formation of ammonia salts and can lead to secondary problems, downstream the flue gas path. Therefore, the ammonia slip should be kept to a minimum.

Since the temperatures over the cross-section in the furnace are rarely uniform, and considerable imbalances are often found, special measures need to be taken to identify the right positions for the injectors to distribute the reagent properly into the flue gas under all operating conditions.

4. SNCR Plant Technology Complying with Standards of Future Legislation

Combustion plants where the first flue gas pass is free of heat exchangers, provide the best conditions for the SNCR technology because the flue gas velocities are low enough to cool down the flue gases in the combustion chamber to the point that 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 district heating plants, etc.

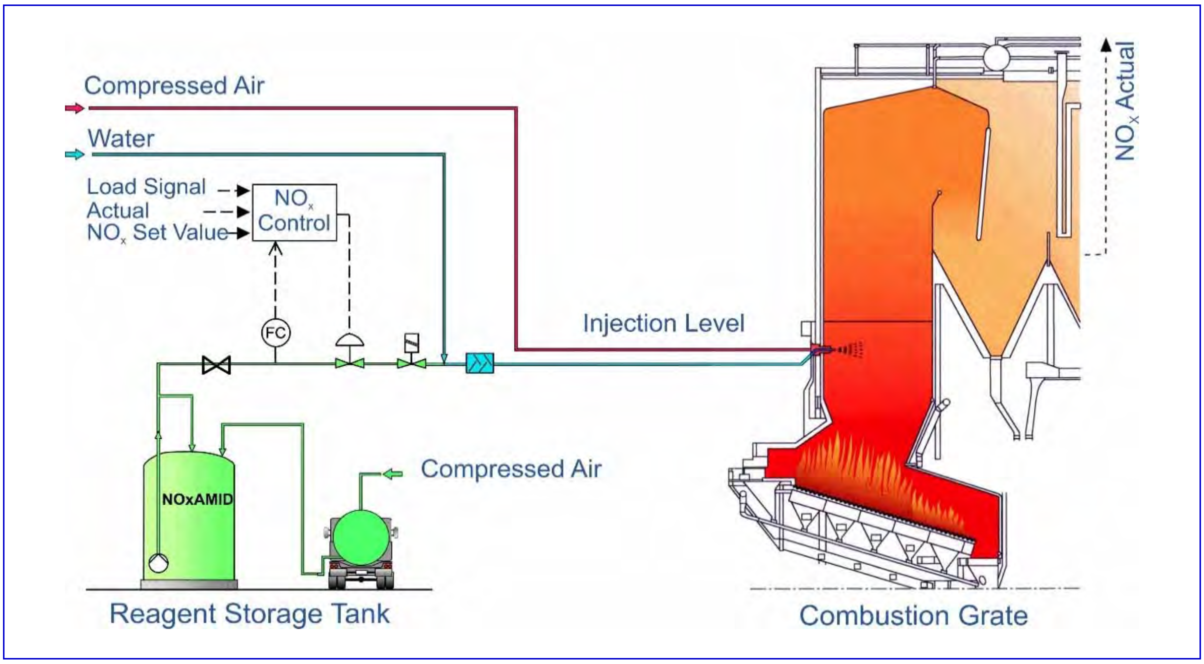
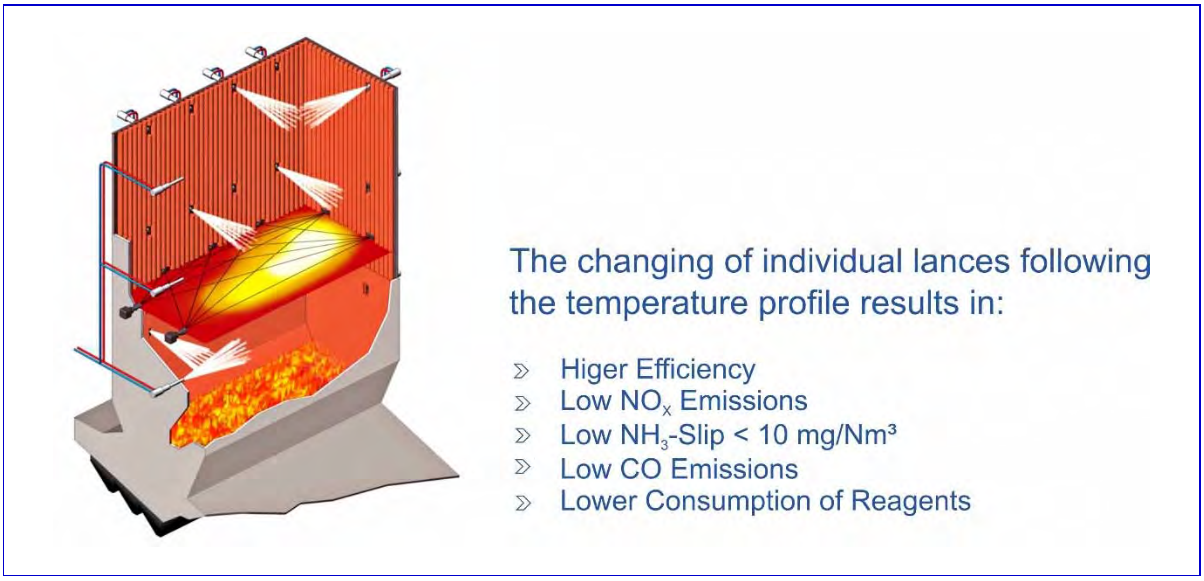


Figure 2: Process flow diagram of a simple SNCR plant

The simplified process flow diagram (**Figure 2**) 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/Nm^3 and NH_3 slip of $< 30\ mg/Nm^3$, 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 from becoming too big during operation, 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 may have a negative impact on the NH_3 slip and the consumption of reagent.



The changing of individual lances following the temperature profile results in:

- Higer Efficiency
- Low NO_x Emissions
- Low NH_3-Slip < 10 mg/Nm³
- Low CO Emissions
- Lower Consumption of Reagents

Figure 3: 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. 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 in these zones. 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_x reduction, NH_3 slip and consumption of reagent (**Figure 3**) can be achieved.

The results that were measured during 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 can be guaranteed and even noticeably better results are possible under favorable operating conditions.

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

A typical example is the Waste-to-Energy plant Wijster in the Netherlands where three SCR plants were decommissioned and replaced with SNCR technology. The fuel remaining after separating bio waste, paper, glass, textiles, etc. has a calorific value of approximately 9 MJ/t and is burnt in three lines with a capacity of 25 t/h each, equivalent to a thermal output of ca. 60 MW (**Figure 4**).

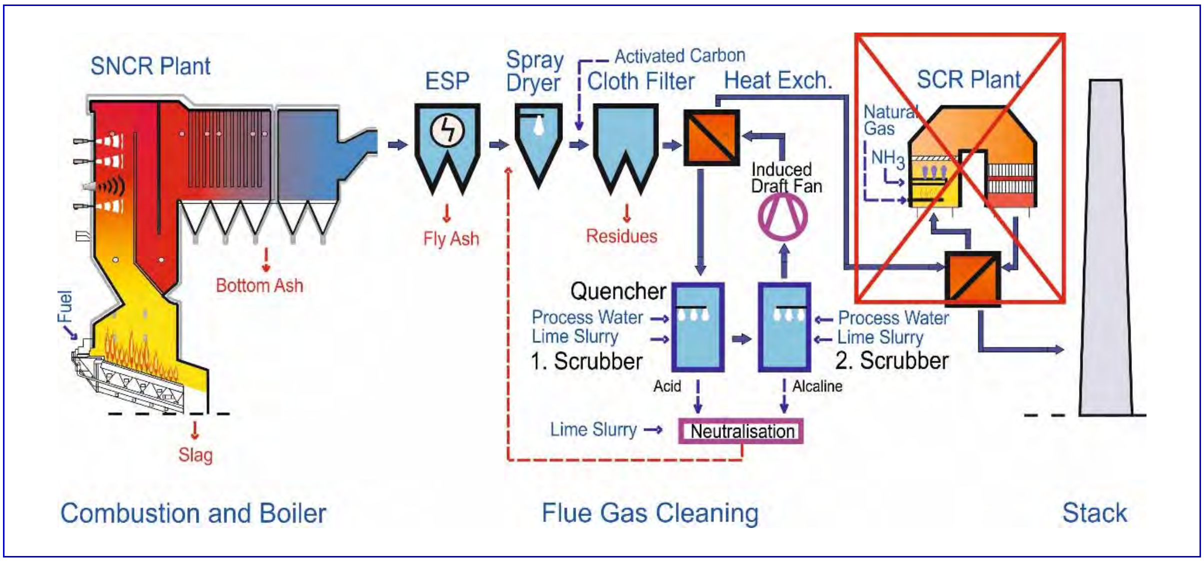


Figure 4: **Waste-to-Energy plant Wijster - Replacement of SCR with SNCR**

Due to the ambitious objectives (NO_x reduction from ca. 300 – 350 mg/Nm^3 to < 60 mg/Nm^3, ref. to 11% O_2, and an NH_3 slip < 10 mg/Nm^3) the installation includes three injection levels with six injectors each per combustion line (**Figure 5**).

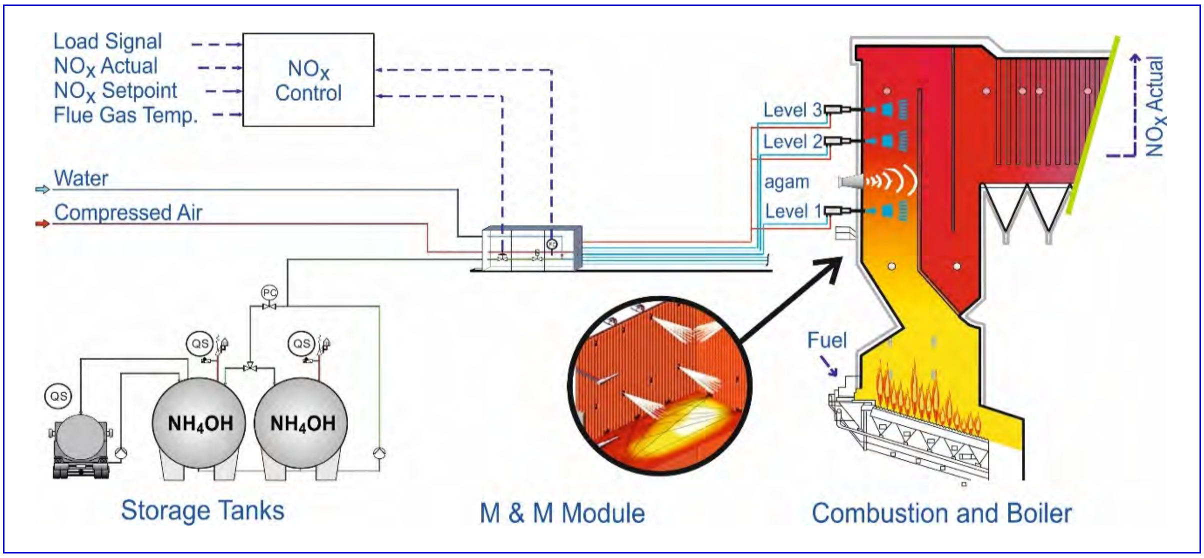


Figure 5: **Process flow diagram - SNCR-plant with agam and three injection levels**

Figure 6 shows the daily NO$_x$ averages of the first SNCR plant and that the emission level of 60 mg/Nm^3 dry, ref. to 11 % O$_2$, could be maintained at all times. During the first six months, the SNCR process achieved an annual NO$_x$ average of < 50 mg/Nm^3 dry ref. to 11 % O$_2$. This result is comparable with the results of the original SCR plant, which reached annual NO$_x$ averages of 45 mg/Nm^3.

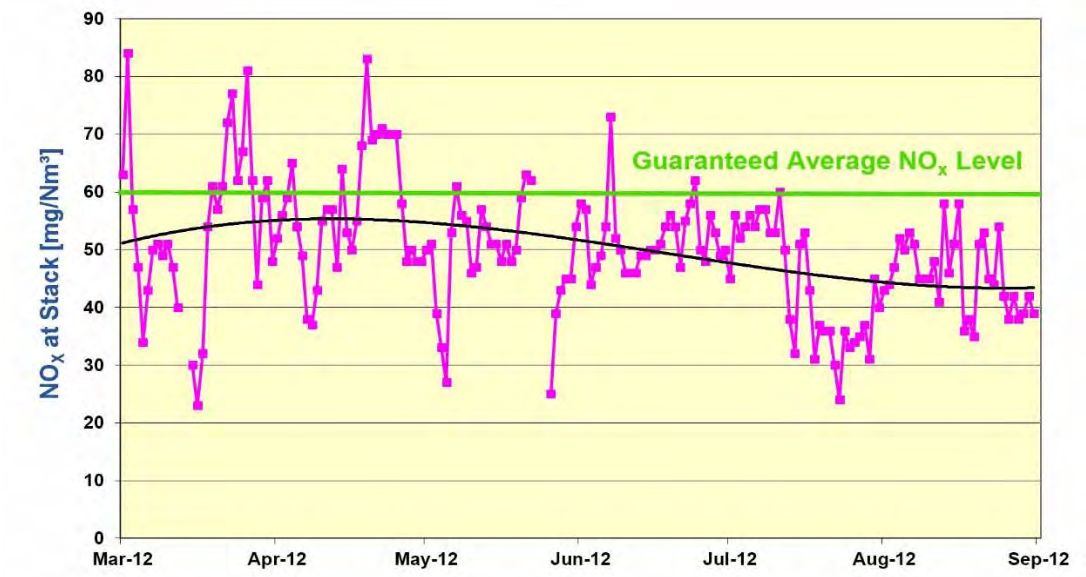


Figure 6: **Waste-to-Energy plant Wijster – Long-term daily NO$_x$ averages**

After installation (**Figure 6**) 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 in the by-product of the flue gas cleaning is much lower than expected. In fact, it is so low that the originally foreseen NH$_3$ stripper for cleaning the waste water became obsolete. The results of the first months of operation are listed in **Table 1** and **Table 2**.

Emissons	Unit	Limit	Operation of three plants
NO$_x$ daily average *	mg/Nm^3	100	23 to 84
NO$_x$ annual average	mg/Nm^3	65	50
NH$_3$ daily average downstream the boiler , respectively upstream flue gas cleaning	mg/Nm^3		15 to > 22
NH$_3$ daily average * at stack	mg/Nm^3	3	0.18

Table 1: **NO$_x$ and NH$_3$ emission levels with SNCR plant** *dry, ref. to 11% O$_2$

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 in Europe (**Figure 7**).


Before Retrofitting

After Retrofitting

Figure 7: Control cabinet of an SNCR in a W-t-E plant retrofitted for NO_x < 150 mg/Nm³

5. Comparing SCR to SNCR for a Waste-to-Energy Plant

The SCR plant in Wijster 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 is approx. 25 mbar. To overcome the pressure drop, a blower consumption of 250 kW per combustion line is required, whereas this additional energy is not needed in an SNCR plant. The temperature loss of the flue gas is approx. 30 K. The power required to raise the temperature again, is provided by gas burners consuming 2,200,000 m³/a of natural gas per plant for this purpose. After removing the three catalysts the flue gas temperature at the stack decreases from 150 °C to approx. 95 °C.

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

Also from the environmental point of view the SNCR technology appears in a positive light: Consuming less energy also means reducing emissions like CO_2 while the NO_x emissions with SNCR are on the same level as with SCR.

As opposed to that, an SCR plant produces additional emissions of 15,000 t / h CO_2 just because it consumes a lot of additional energy which is needed for the higher consumption of electricity of the ID fans and for the gas fired duct burners.

Operating Data	**Unit**	**SCR NH_4OH (24.5 %)**	**SNCR NH_4OH (24.5 %)**
Throughput of waste	t/h	25	25
Flue gas volume flow	Nm^3/h (tr.)	100,000	100,000
Operating hours	h/a	8,000	8,000
NO_x raw gas concentration	mg/Nm^3	330	330
NO_x clean gas concentration	mg/Nm^3	45	50
NO_x reduction per line	kg/h	28.5	28
NO_x reduction (three lines)	t/a	684	672
Ammonia water 24.5 % (three lines)	t/a	800	4,000
CO_2 (three lines)	t/a	12,000	
Consumption of compressed air incl. agam	Nm^3/h		500
Consumption of deionized water	m^3/h		1.2
Additional electrical consumption by ID fan	MWh/a	6,100	
Consumption of natural gas	Nm^3/a	6,600,000	

Table 2: Operating data – SCR versus SNCR

Table 2 indicates that operating costs for reducing 1 ton of NO_x are by far higher when using SCR technology than in an SNCR plant. From other studies it can be concluded that the investment costs for SCR are 5 to 10 times higher than for SNCR which shows that an SNCR plant with its better cost-benefit ratio is more economical and therefore much more effective protecting the environment.

6. Commercial Application for a Coal-Fired Boiler (225 MW_{el}) in Jaworzno, Poland

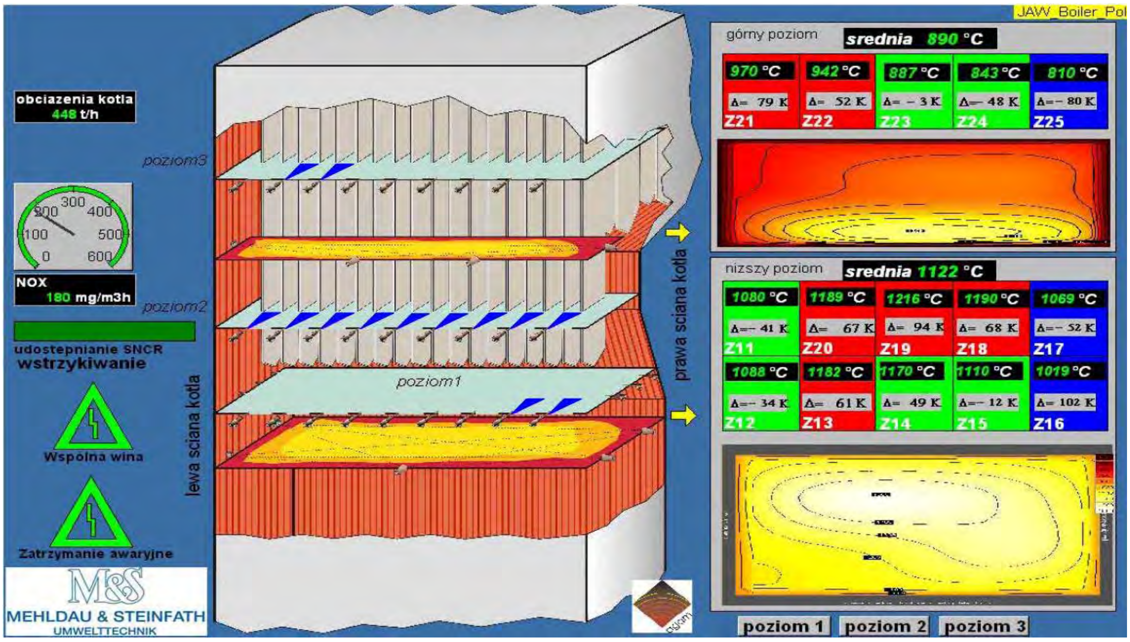
At the power plant Jaworzno in Poland, six coal fired boilers of the same type (OP 650) (**Figure 8**) have been retrofitted with low NO_x burners and SNCR.

Design Data

Burner Configuration		Front Firing
Capacity	[MW_{el}]	225
Flue Gas Volume	[m³/h]	740,000
Fuel		Coal
SO_2	[mg/Nm³]	800 – 2,000
NO_x @ 6 % O_2 without SNCR	[mg/Nm³]	250
NO_x @ 6 % O_2 with SNCR	[mg/Nm³]	190
NH_3 with SNCR	[mg/Nm³]	5
Load Range		60 – 100 %

Figure 8: Design data of a coal-fired boiler with front firing in Jaworzno, Poland,

In order to follow the load changes of the boiler, three injection levels were installed. Because of the extreme temperature imbalances which were measured before starting the design of the SNCR, an acoustic temperature measurement system (agam) with two levels was installed (**Figure 9**)



górny poziom — srednia 890 °C

Z21	Z22	Z23	Z24	Z25
970 °C	942 °C	887 °C	843 °C	810 °C
Δ= 79 K	Δ= 52 K	Δ= – 3 K	Δ=– 48 K	Δ=– 80 K

nizszy poziom — srednia 1122 °C

Z11	Z20	Z19	Z18	Z17
1080 °C	1189 °C	1216 °C	1190 °C	1069 °C
Δ=– 41 K	Δ= 67 K	Δ= 94 K	Δ= 68 K	Δ=– 52 K
Z12	**Z13**	**Z14**	**Z15**	**Z16**
1088 °C	1182 °C	1170 °C	1110 °C	1019 °C
Δ=– 34 K	Δ= 61 K	Δ= 49 K	Δ=– 12 K	Δ= 102 K

Figure 9: Display with temperature profiles in 2 levels, injectors in operation, perfomance data

Temperature imbalances of up to 200 K were measured from the right to the left side of the combustion chamber.

The first SNCR plant was commissioned successfully in March 2012 and handed over to the operator shortly after. The plant is operating commercially since then to the satisfaction of the customer.

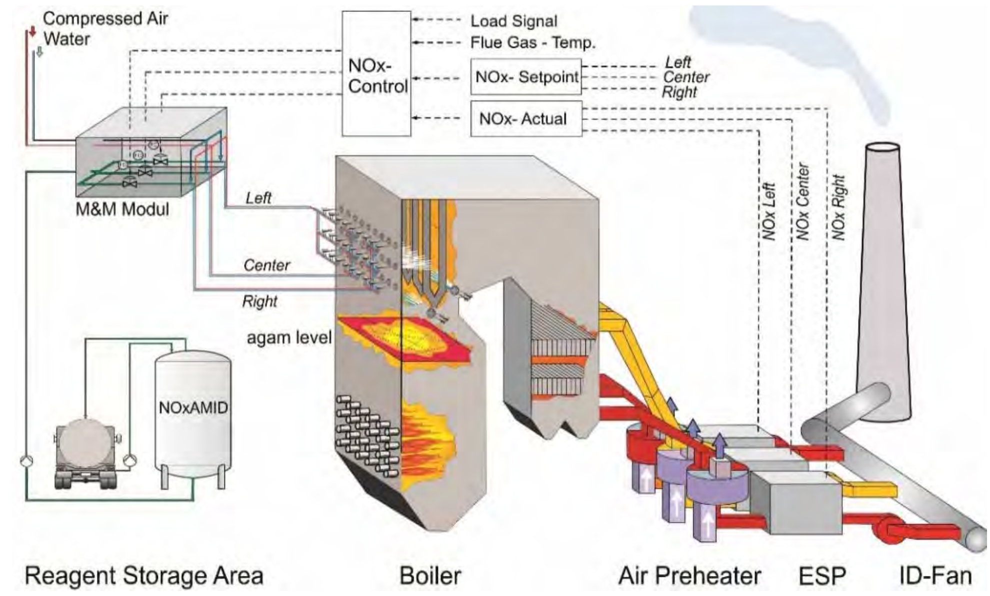


Figure 10: Simplified flow diagram of an SNCR for a coal-fired boiler in Jaworzno

The other five were completed one by one until March 2016. Since it became obvious during the commissioning that the flue gas temperatures at full load are higher than expected, the upper injection level for the other boilers were moved up to a higher level where the temperatures are lower. It turned out that there are also considerable imbalances of NO_x concentrations. In order to optimize the performance of the SNCR, three control valves were installed (**Figures 10 and 11**). This results in lower ammonia slip both in the flue gas and the flue ash and decreases the consumption of reagent (urea solution).

In combination with the primary measures the required NO_x level < 200 mg/Nm^3 is maintained at all operating conditions.

Figure 11: Lances

Mixing and metering module for SNCR in Jaworzno

7. Solutions for a Further Improved SNCR Performance

7.1. NO_x Reduction with Urea and/or Ammonia – The TWIN-NO_x® Process

After the general decision has been taken in favor of SNCR, it is as important to select the best reagent for each application. The availability, logistics and cost of urea compared to ammonia water are important arguments. But more often, there are reasons from the process point of view which should be considered since both reagents have their specific advantages and disadvantages depending on the specific application.

The major difference between ammonia water and urea solution is shown in a strongly simplified diagram in **Figure 12**. Urea dissolved in water can only be decomposed into reactive NH_2 species after the water enclosing the urea particles has been completely evaporated. The place in the flue gas where the reaction is to take place can be defined in advance by means of the water droplet size and the resulting penetration depth. If the water droplet is big enough, it is possible to inject into a place that is too hot for NO_x reduction, because the reagents are released at the end of droplet trajectories in a colder place within the flue gas. The mass of the dilution water, which is additionally used as a carrier medium for urea solution, ensures a high penetration depth at rather low energy consumption, and may in some cases cool down the flue gas to the desired temperature, if necessary. Since urea is very corrosive, impingement of the droplets on the heating surfaces has to be avoided.

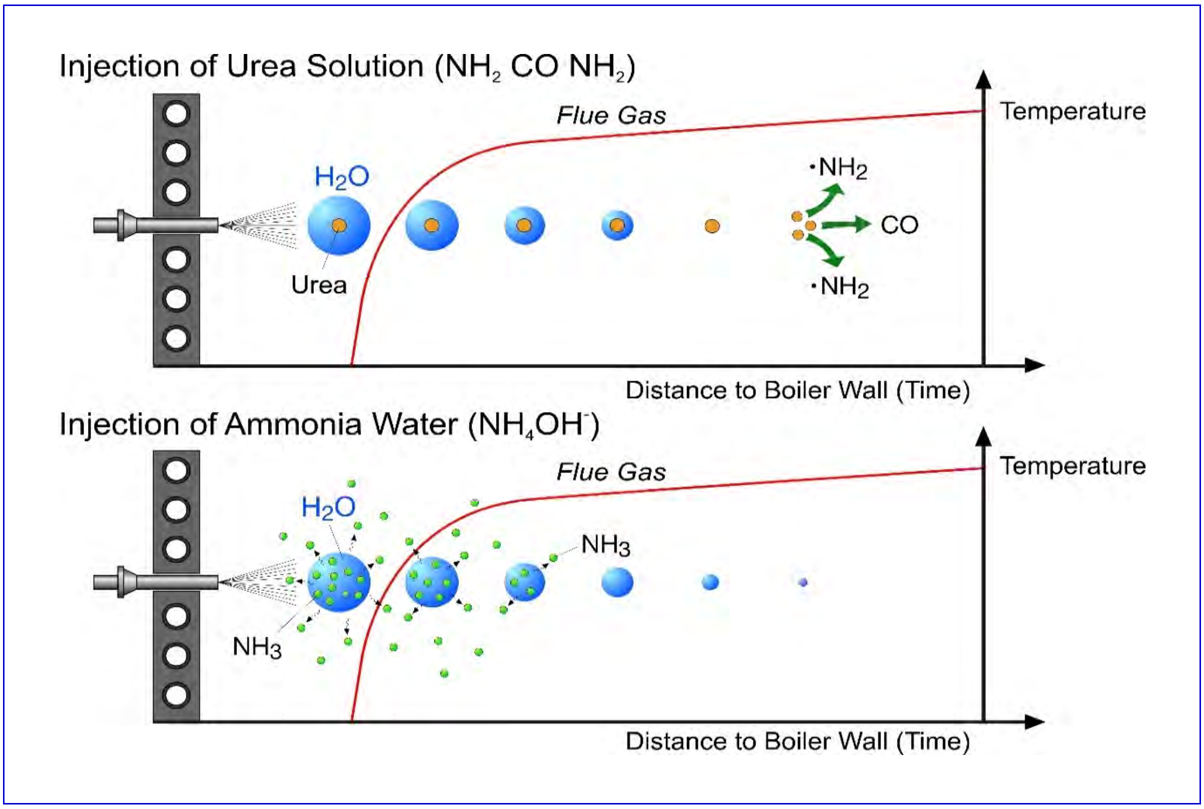


Figure 12: NO_x reduction: urea versus ammonia water

As opposed to urea, ammonia is a highly volatile reagent which is released near the source of the droplet, which is immediately after the ammonia water has entered the furnace. The NO_x reduction will then mainly take place in the cooler area near the boiler walls where it is more likely that ammonia slip is generated. To ensure an optimum penetration depth, more energy is required because of the lower mass of ammonia in gaseous form compared to water droplets. In traditional plants this is accomplished by increasing the volume of steam or compressed air used as a driving medium.

However, a homogeneous distribution is still very difficult to obtain as flue gases are very viscous and it is therefore difficult to mix different gases. This disadvantage, which has often caused a higher ammonia slip in SNCR plants using ammonia water, can be compensated for to a great extent when dilution water is used as a carrier medium also for ammonia water.

The higher mass flow of water decreases the pressure in the jet stream downstream of the nozzle, compared to using compressed air or steam alone **(Figure 13)**. Due to the resulting pressure difference, the surrounding flue gas is mixed with the reagent. This concept produces similar results with regard to NO_x reduction and ammonia slip compared to applications where urea is used as reagent.

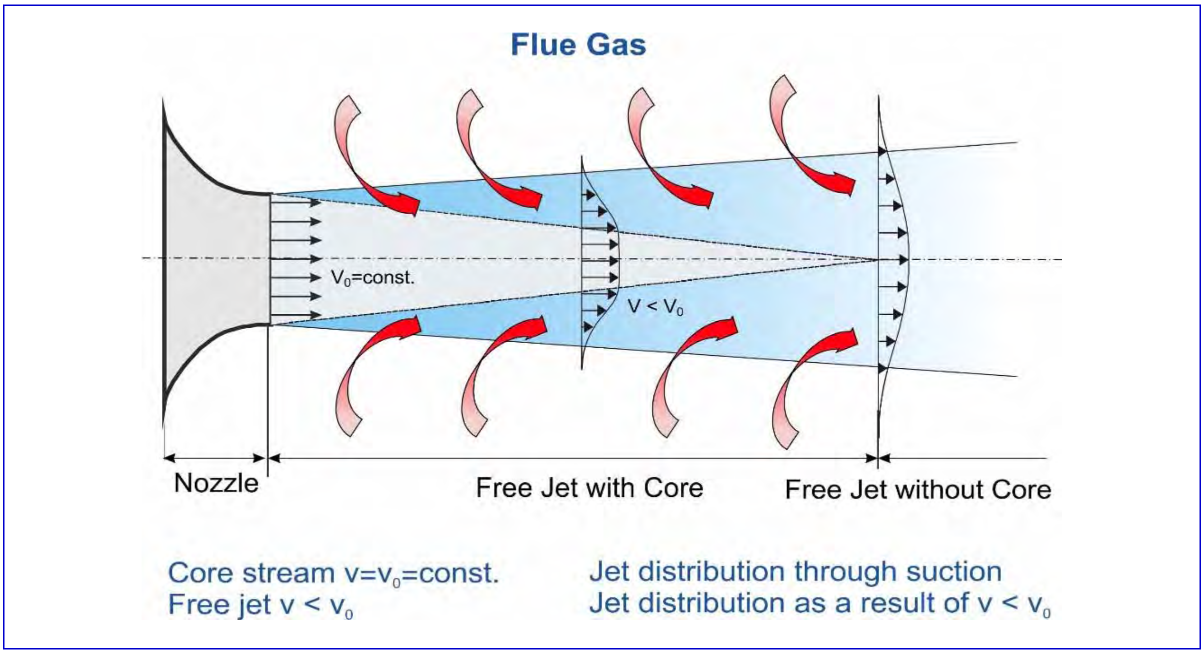


Figure 13: Mixing flue gas with free jet

Urea solution was used as reagent during the testing of the SNCR process in the 200 MW_{el} coal fired boiler in Germany, while the commercial plant was built for ammonia water. However, especially at full load, the operating results with the commercial plant were below expectations.

During commissioning the automatically controlled plant did not provide better results than achieved with the manually controlled trial equipment. The only significant difference between the two systems is that ammonia water is used as reagent for the commercial plant instead of urea solution. The assumption that the performance of urea is better for this application than ammonia water was based on the fact that the reagent (ammonia) reacts too close to the boiler wall and does not reach the area with the optimum temperature.

In order to verify this assumption, additional tests with urea were performed in the commercial plant as well. The realization was easy, since the reactivity and consequently the flow rate of urea solution (45 %) is almost identical to ammonia water (25 %) so that the equipment and settings of the control system and instrumentation do not need to be changed for the application of the other reagent.

The results showed that immediately after injection of urea the NO_x reduction increased and the consumption of the reagent decreased (**Figure 14**). This indicated at first glance that for this special boiler design urea is the preferable reagent with regard to the NO_x emission values at full load and when the effective temperature window lies between the heat exchangers. On the other hand, there was still a concern that there is a higher risk applying urea with regard to impingement and corrosion of the boiler tubes.

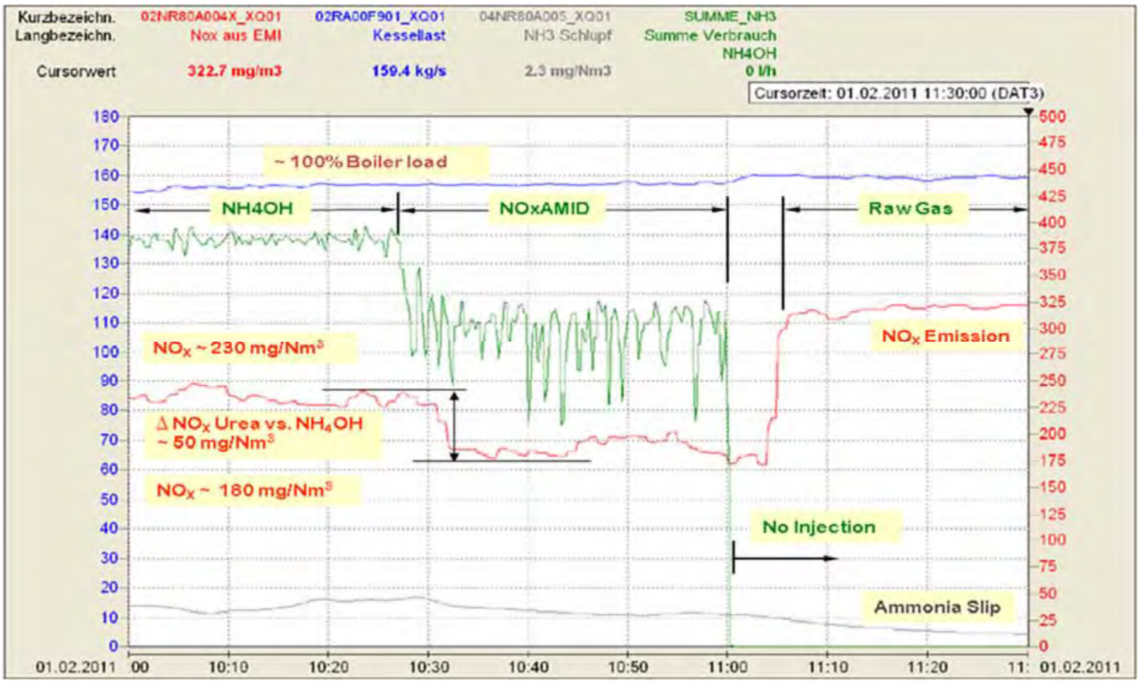


Figure 14: Operating results – Injection with NO_xAMID

The objective of further tests was to verify the expected advantages and disadvantages respectively to confirm the different behavior of ammonia water versus urea solution.

The tests confirmed that the low volatility reagents (NO_xAMID) are indeed released at the end of the droplet trajectories while the high volatility reagents (NH_3) are released near the droplet source close to the boiler walls. Further tests showed that by changing the reagents depending on the operating conditions the performance of the SNCR could be improved considerably.

Thereafter, it was a logical consequence to mix both reagents together and inject various mixtures into the furnace, in order to combine the respective features (**Figure 15**).

Now two commercial plants have been built, one burning coal and the other one oil, which can be operated alternately or simultaneously with urea solution and/or ammonia water in order to combine the advantages and the special features of the two reagents. The results summarize in a more effective and wider temperature and load range, higher efficiency, lower ammonia slip, less consumption of reagent and minimum risk of corrosion. Because of the combination of two reagents the new process is patented and named TWIN-NO_x® now.

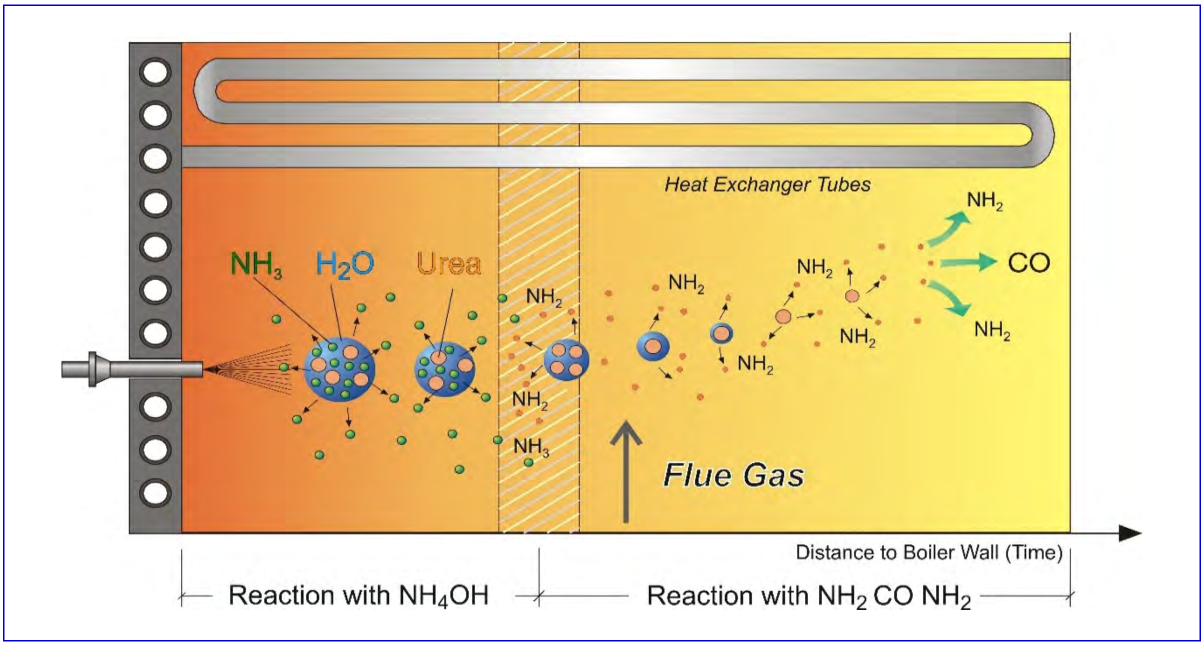


Figure 15: NO_x reduction - Mixing of ammonia water (NH_4OH) and urea (NH_2 CO NH_2)

8. Providing SNCR Friendly Operating Conditions

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 spread, 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 also might be an effective and viable alternative to cool down the flue gases to a level where NO_x reduction is possible at all operating conditions.

8.1. Cooling of the Flue Gases with Additional Water

Since in Waste-to-Energy plants NO_x levels < 100 mg/Nm³ are state-of-the-art today, the potential for further developments is highest in larger combustion plants, where the flue gas temperatures are too hot in those areas which are accessible for injecting the reagents. A feasible measure could 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.

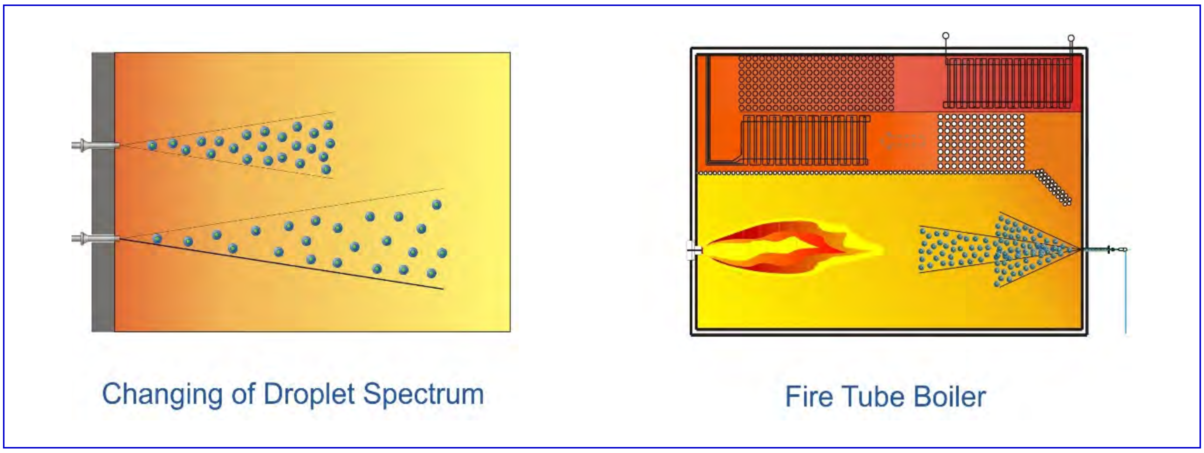


Figure 16: Flue gas cooling by inreasing the quantity of cooling water

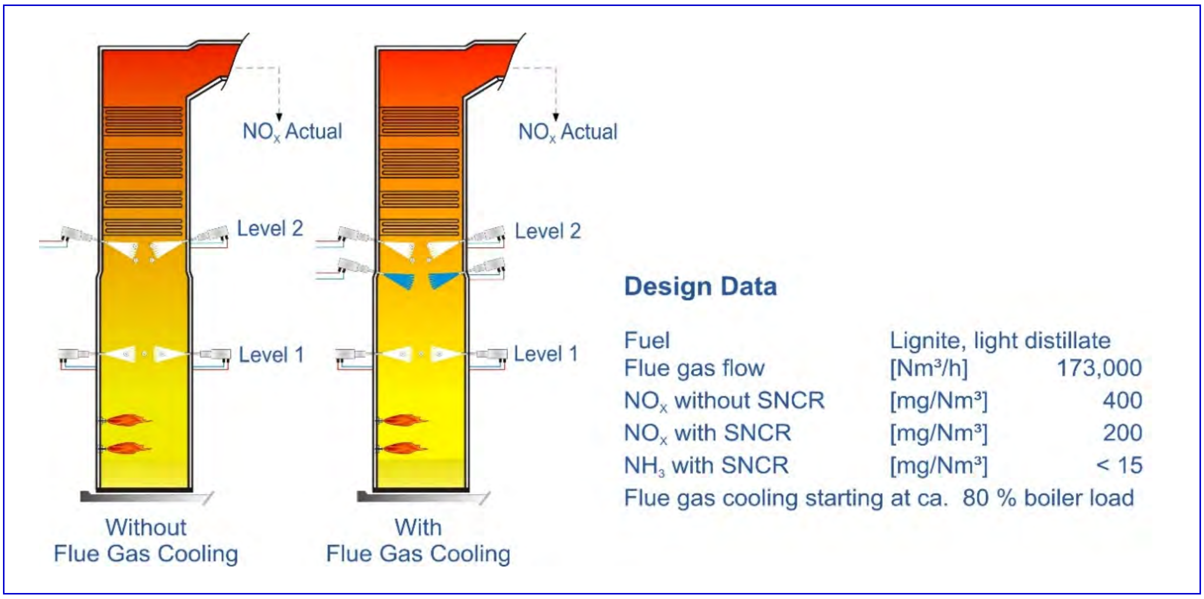
A continuous operation of the boiler with an increased amount of water is acceptable only as an exception, because vaporizing the water consumes a lot of energy (one ton of water equals one ton of steam) and affects the efficiency of the combustion plant (**Figure 16**).

Controlling the quantity of water depending on boiler load respectively temperature is a standard procedure and has been practiced since many years in fire tube boilers. The disadvantages mentioned above 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 in order to follow the changes of the flue gas temperatures.

In larger boilers where the reagent is practically always injected from the side walls across 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 17**).

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 at the injection of reagent is not changed, but the disadvantage is that temperature imbalances can lead to a higher

NH_3 slip in areas which are colder. The effect would be an increase of NH_3 slip, a waste of cooling water and a lower efficiency.



Design Data

Fuel	Lignite, light distillate	
Flue gas flow	[Nm^3/h]	173,000
NO_x without SNCR	[mg/Nm^3]	400
NO_x with SNCR	[mg/Nm^3]	200
NH_3 with SNCR	[mg/Nm^3]	< 15

Flue gas cooling starting at ca. 80 % boiler load

Figure 17: Coal-fired boiler with and without flue gas cooling

Preferably, this method should be applied only 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 an additional injection level can be avoided in many cases.

9. Most Recent Developments of NO_x Reduction with SNCR

9.1. Selective Cooling of Flue Gases

“Selective Cooling” is a major step ahead. It also requires an additional injection level for cooling water beneath the top injection level, but it improves the efficiency of this additional level. The major difference is that Selective Cooling reacts to temperature imbalances by injecting cooling water only in those areas which are too hot. Individual lances or groups of lances are activated depending on the temperature profile generated by a suitable temperature measurement system (**Figure 18**).

Figure 19 shows the results of the Selective Cooling in a coal-fired boiler in the Czech Republic. With additional cooling water alone, the NO_x reduction of the SNCR could be increased by an additional 120 mg/Nm^3 to a level of < 160 mg/Nm^3.

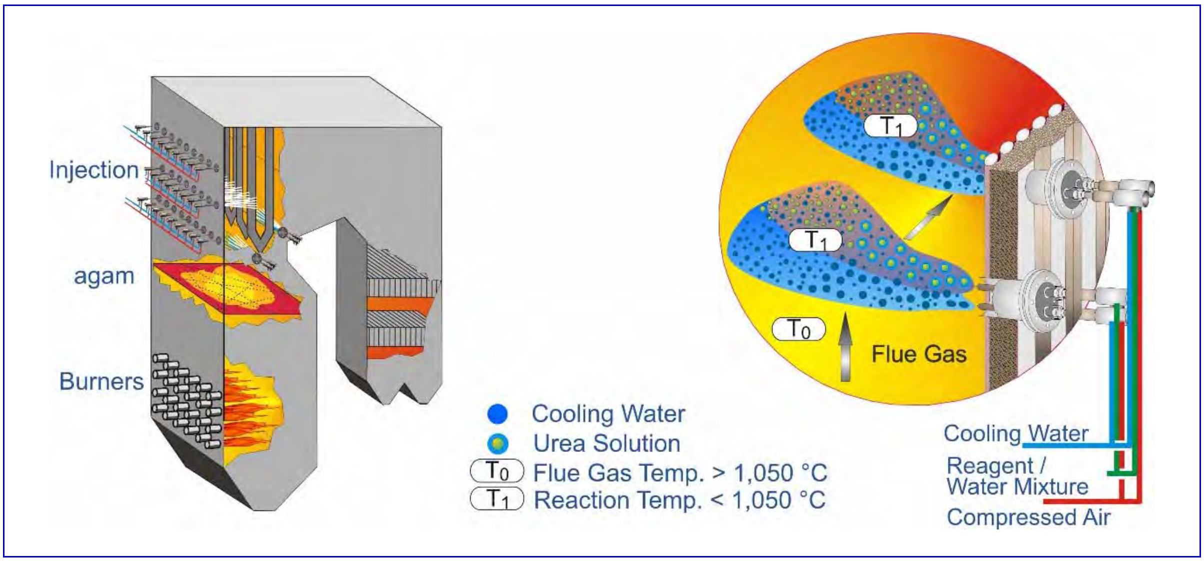
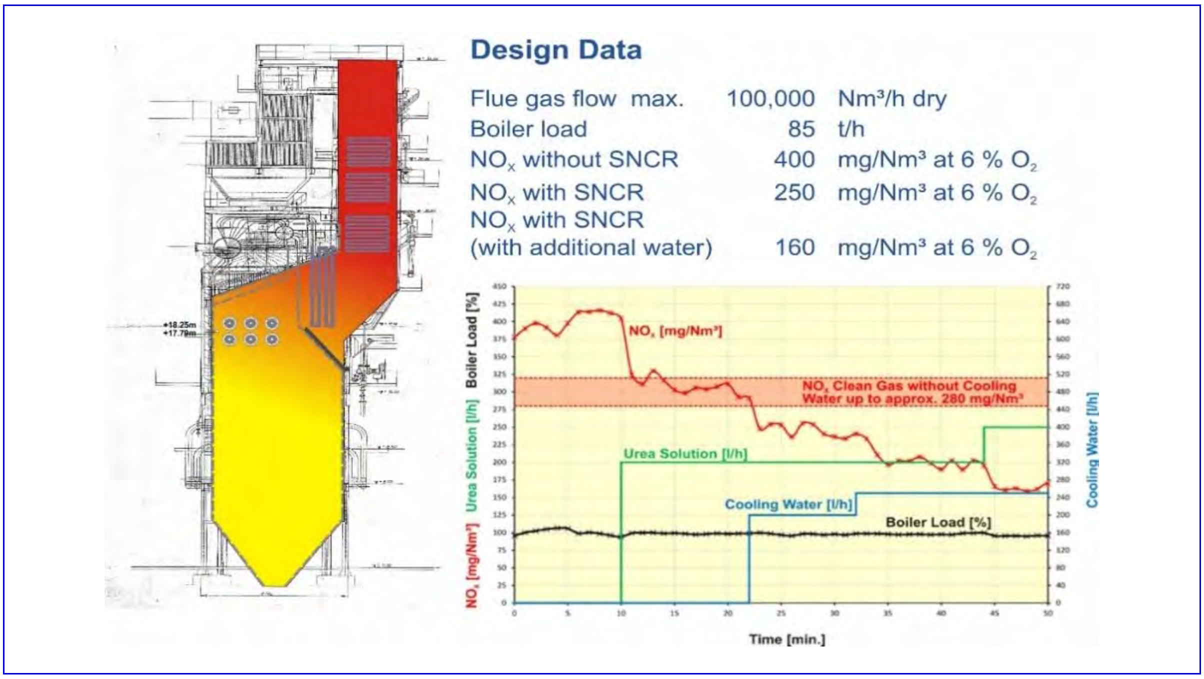


Figure 18: Selective flue gas cooling for coal-fired boilers



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

9.2. 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 improve the performance of SNCR by cooling down the flue gases.

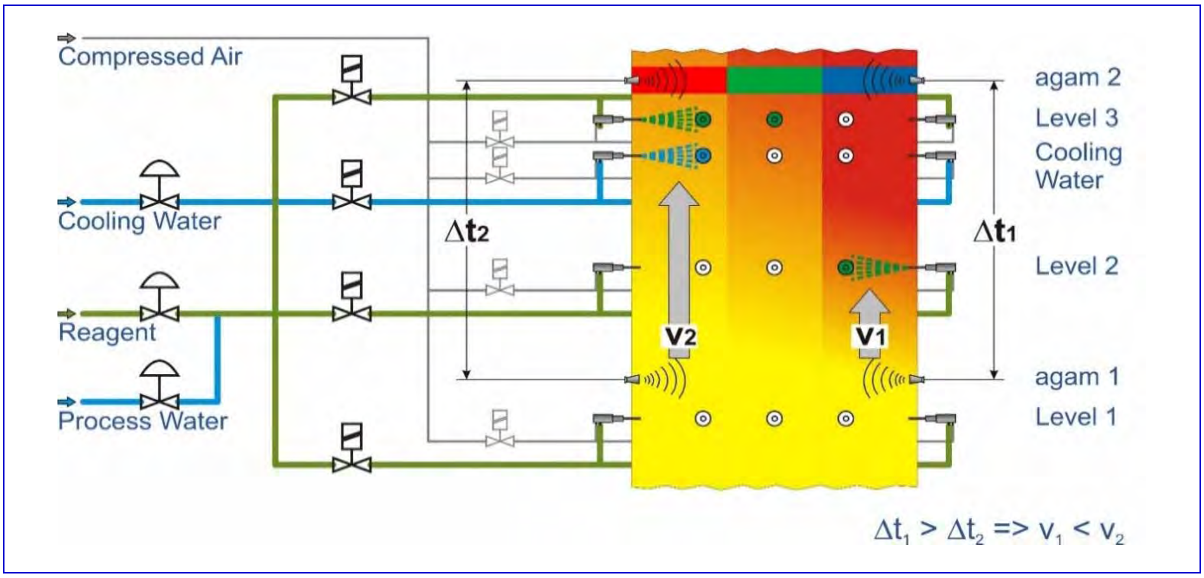


Figure 20: Principle of adaptive flue gas cooling

However, a better solution is to control the amount of water more precisely in order to further decrease the consumption of cooling water.

To realize this objective 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 20**).

The temperatures are constantly being measured online and average flue gas temperatures are calculated in defined sections which are assigned to single injectors or groups of injectors.

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

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, i.e. reagent/water-mixture and cooling water, can be measured. Based on the various temperatures the flow of cooling water can be adapted as needed to maintain the optimum temperatures within the injection level in order to obtain efficient NO_x reduction and low ammonia slip. Furthermore, the activation of the lances for reagent can be determined more precisely when temperatures are measured in two levels.

To achieve this, another temperature measurement system has to be installed for measuring the flue gas temperatures above the lowest injection level as described for the top level.

9.2.1. Defining Flue Gas Velocity

It is often neglected that apart from the flue gas temperatures, the flue gas velocities at different injection positions, 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 [mg/Nm^3] * flue gas flow [Nm^3/h],

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 to decrease the consumption of reagent and minimize ammonia slip.

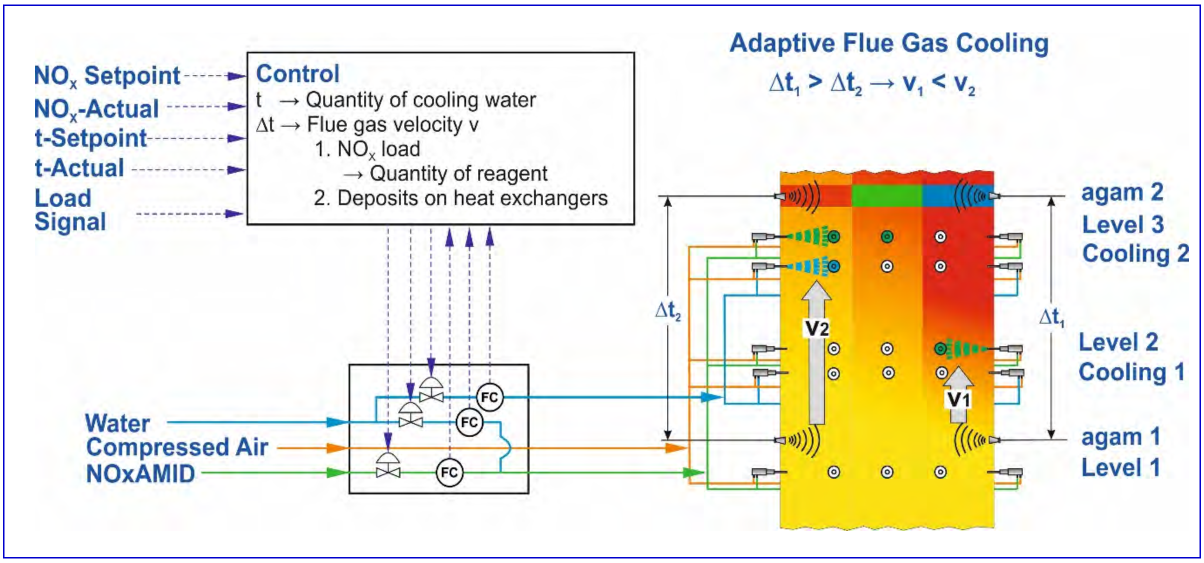


Figure 21: Adaptive flue gas cooling – Extrapolating flue gas velocities from differences in temperature

With this arrangement of the temperature measurement systems in two levels (**Figure 21**), the temperatures in the 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 corresponding 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 into a further optimized distribution of the reagent across the furnace for better performance of the SNCR.

10. Summary and Outlook

In smaller combustion plants like those that burn waste or biomass, the SNCR process has been well established and accepted as Best Available Technology (BAT) since many years. In the meantime, the operating experiences in large combustion plants with a capacity of > 200 MW_{el} have shown that the NO_x levels required under the new EU legislation from 2016 on can reliably be reached.

Recent techniques like the changing of individual lances, the TWIN-NO_x® process, the Selective Cooling and Adaptive Cooling of flue gases in combination with primary measures have produced results which indicate further potential for improvements. Currently, there is an increasing demand for plants that have boilers with an output of 300 to 500 MW_{el} and emission levels of < 150 mg/Nm^3 and NH_3 slip < $5mg/Nm^3$.

11. Literature

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