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WASTE MANAGEMENT

Volume 6

Waste-to-Energy

Bibliografische Information der Deutschen Nationalbibliothek

Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.dnb.de abrufbar

Thomé-Kozmiensky, K. J.; Thiel, S. (Eds.): **Waste Management, Volume 6**
– Waste-to-Energy –

ISBN 978-3-944310-29-9 TK Verlag Karl Thomé-Kozmiensky

Publisher: TK Verlag Karl Thomé-Kozmiensky • Neuruppin 2016
Editorial office: Professor Dr.-Ing. habil. Dr. h. c. Karl J. Thomé-Kozmiensky, Dr.-Ing. Stephanie Thiel, M. Sc. Elisabeth Thomé-Kozmiensky, Janin Burbott-Seidel und Claudia Naumann-Deppe
Layout: Sandra Peters, Anne Kuhlo, Janin Burbott-Seidel, Claudia Naumann-Deppe, Ginette Teske, Gabi Spiegel und Cordula Müller
Printing: Universal Medien GmbH, Munich

New Developments for an Efficient SNCR Monitoring and Regulation System by Evaluating the NO_x Mass Flow Profile

Bernd J. von der Heide

When the SNCR process was introduced first in the eighties of the last century the focus was directed towards applying this low cost technology mainly in combustion plants where only relatively low NO_x reduction rates were required. In these types of boilers, like waste-to-energy plants (WtE), the required NO_x limits < 200 mg/Nm^3 could be maintained easily. Today, NO_x limits of 100 mg/Nm^3 and lower can be achieved and guaranteed at all operating conditions for these applications. Therefore, the SNCR process represents the *Best Available Technology* (BAT) today. As a result, more and more owners of waste-to-energy plants take advantage of the low costs at comparable performance and replace their existing SCR system with SNCR.

Motivated by this successful development, an increasing number of utility companies have already also installed SNCR plants or are seriously investigating to use this technology for their large boilers as well.

This paper shows that the SNCR process is an attractive alternative for various fuels and types of combustion sources, especially if the results and experiences which were gathered to date, are applied and consequently developed further to meet the ambitious demands of the regulators.

1. Influences of design and operating conditions on performance of SNCR

In theory the SNCR process seems to be very simple. However, the practical realization is often rather complex. In order to comply with the current emission limits for NO_x and the more stringent limits to be expected in the future, the SNCR technology has to be improved continuously. In order to find solutions a better understanding of the combustion process, the boiler design and the flue gas flow and composition is required.

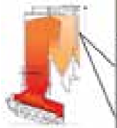
Especially following parameters determine the performance of SNCR:

- The boiler design, which in many cases prevents the reagents from being injected and distributed into the flue gas at the right temperatures,
- The design of the combustion chamber,
- The design and configuration of the burners,
- The operating conditions of the boiler,
- The type of fuel,
- The flue gas – composition, velocity, direction of flow, temperature profile,
- The reagent – urea solution or ammonia water,
- The required NO_x reduction and ammonia slip,
- Ammonia in the fly ash and by-product of flue gas cleaning.

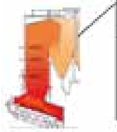
2. Steps for the development of SNCR technology

Combustion plants where the first flue gas pass is free of heat exchangers are most suitable for the SNCR technology. The reason 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.

1 Level



3 Levels



Application	Load %	NO_x baseline mg/Nm³*1	NH_3 slip mg/Nm³*1	Injection levels	Remarks
Small combustion plants	80 – 100	< 200	< 20	1	Urea tank in module
Moderate NO_x reduction	90 – 100	< 200	< 15	1	
Moderate NO_x reduction	60 – 100	< 150 – 200	< 15	2	
High NO_x reduction	50 – 100	< 100 – 150	< 15	3	
High NO_x reduction, low NH_3 slip	50 – 100	< 100	< 5 – 10	3	Acoustic temperature measurement (agam)

*1 Ref. actual O_2

2 Levels

3 Levels with agam

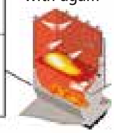


Figure 1: SNCR concepts for different applications

Figure 1 shows the development steps of typical SNCR plants operating with urea solution or ammonia water as reagent. Plants which are operating according to the German regulation (17. BImSchV) with NO_x reduction rates up to sixty percent are – depending on the specific requirements – equipped with one or two injection levels which are alternatively activated depending on boiler load and/or flue gas temperatures.

This concept reliably allows meeting NO_x limits of 120 to 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. 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 too large temperature variations and imbalances 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 can have a negative impact on NH_3 slip and the consumption of reagent.

After determining the temperature profile of the whole cross-section of the injection level, it is divided into various zones and assigned to defined lances or groups of lances which are activated depending on the average 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 in which optimum results regarding NO_x reduction, NH_3 slip and consumption of reagent can be achieved (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 can be guaranteed and even noticeably better results are possible.

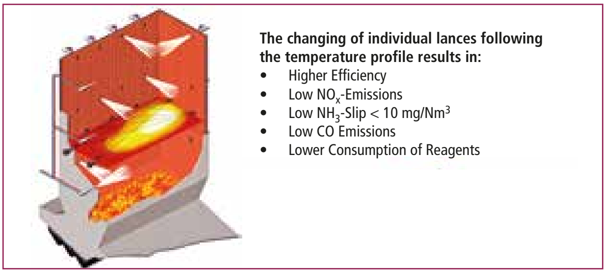


Figure 2:

Temperature controlled changing of individual lances

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.

3. Operating experiences with various boilers

3.1. Operating experiences with a Waste-to-Energy plant (WtE)

In the Netherlands the waste-to-energy plant (WtE) in Wijster had been operating with SCR to reduce NO_x since 1996. Because of the favorable cost-benefit-ratio of the SNCR technology the operator decided to replace the existing SCR systems with an SNCR plant (Figure 3). Apart from the economic advantages, the precondition for this decision was that the NO_x emissions approved by the authorities for the SCR would also be maintained for SNCR.

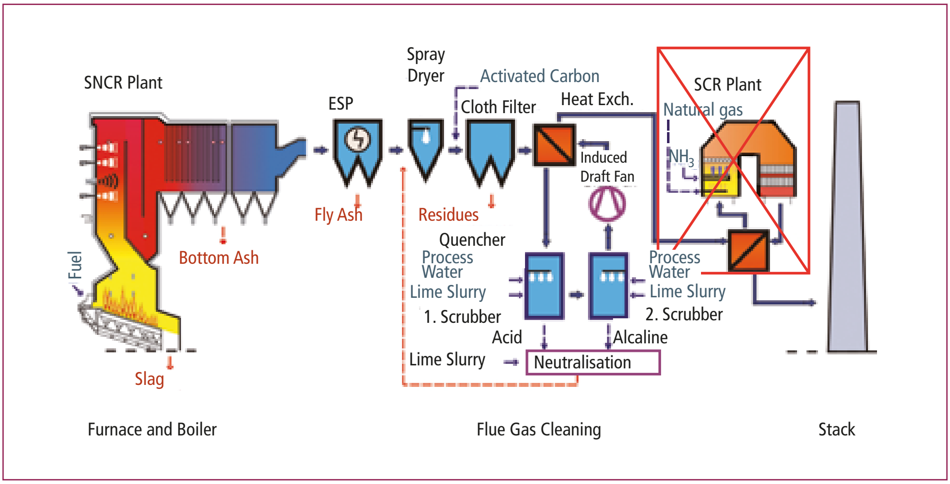


Figure 3: Flow chart for Waste-to-Engergy plant Wijster – SCR was replaced by SNCR

The plant consists of three lines with a capacity of burning 25 t/h of municipal waste per incinerator. The NO_x baseline is approximately 330 mg/Nm³. The guaranteed NO_x level after SNCR is < 60 mg/Nm³. The injectors which are installed on three levels are individually activated based on the flue gas temperatures measured with an acoustic gas temperature measurement system (agam) (Figure 4).

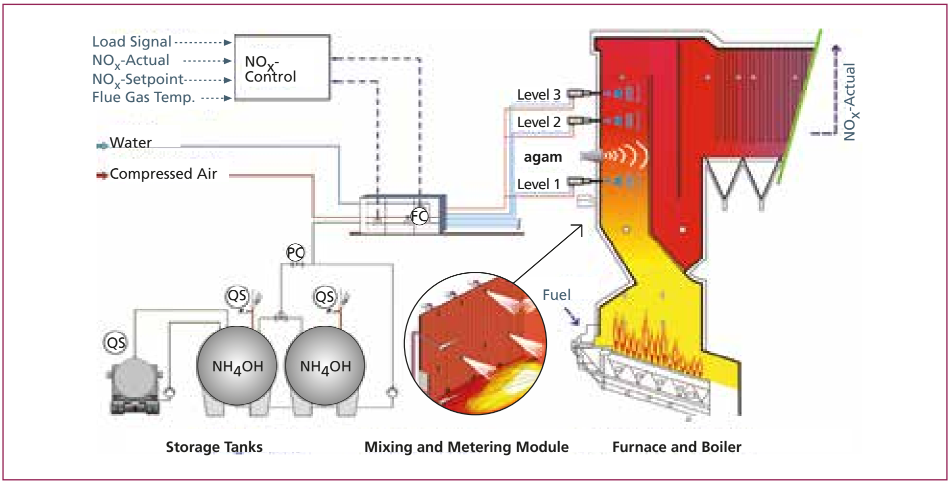


Figure 4: SNCR Plant with acoustic temperature measurement system and three injection levels

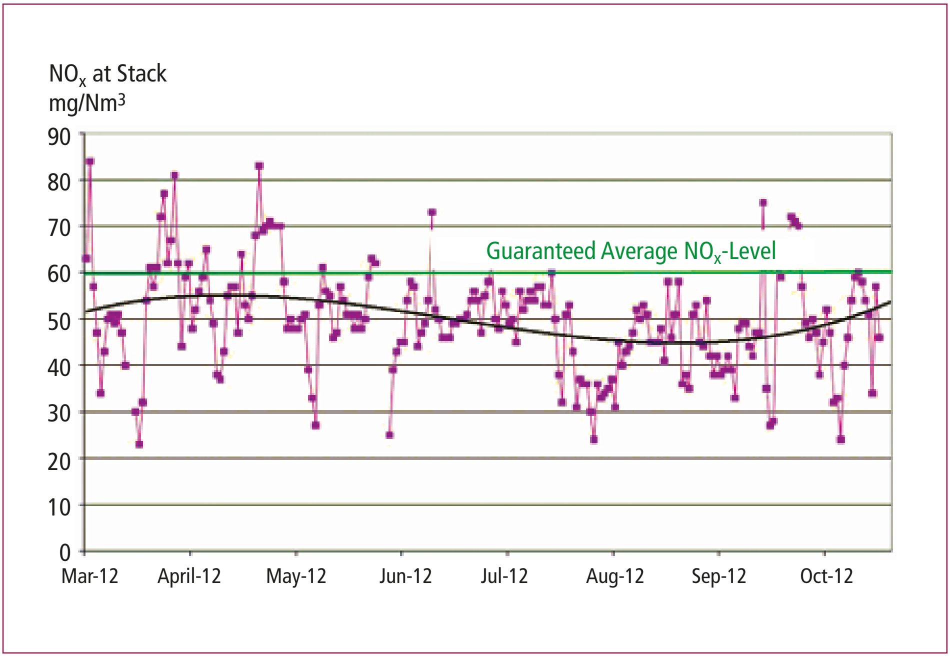


Figure 5: Daily averages line 11 – March to September 2012

Compared to the SCR, the savings of natural gas for reheating the flue gas upstream the catalyst are 6.6 million Nm^3 per year and approximately 6,100 MWh per year savings in electricity, since no energy is needed to overcome the pressure drop in the catalyst.

The first combustion line was put into operation in March 2012, the second one in September 2012 and the third one in April 2013. All SNCR plants are operating to the full satisfaction of the operator at extraordinarily low NO_x emissions of 50 mg/Nm^3 (Figure 5).

3.2. Liquid fuel

Boilers fired with liquid fuels usually have smaller combustion chambers than grate-fired boilers with the same capacity. This results in higher temperatures and velocities of the flue gas before entering the heat exchangers. The design of an SNCR is therefore more challenging.

Combustion plant for liquid waste

Figure 6 shows two boilers which burn liquid waste with a wide range of fuel composition. The first boiler (No. 7) was put into operation 2004, the other one (No. 8) was commissioned at the end of 2014. The profiles of the flue gas flow and the temperature illustrate the challenges to distribute the reagent properly in the flue gas in order to achieve the NO_x emissions < 60 respectively 80 mg/Nm^3 under all operating conditions.

In order to avoid turbulences and back flows of the flue gases which cause the temperature imbalances in boiler 7, boiler 8 was built without heat exchangers in the second pass (Figure 7). In boiler 7 the injectors were relocated after several tests close to the boiler wall where the velocity is fastest and the NO_x freight is highest.

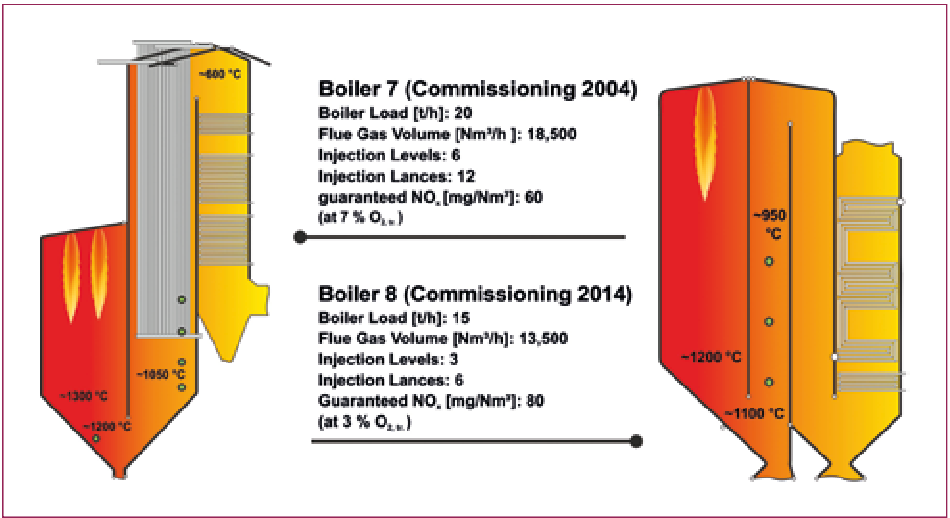


Figure 6: Operating data and boiler design for liquid waste

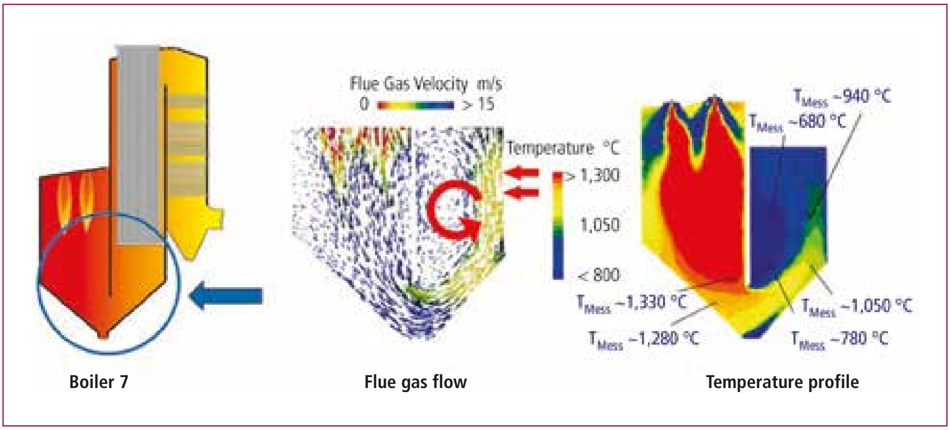


Figure 7: Flue gas flow and temperature profile in a boiler for liquid waste

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,
- Boiler design which facilitates retrofitting of the combustion plants with SNCR,
- Reducing boiler load,
- Cooling of 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 modified, which is usually a very costly undertaking. For new installations, the specific requirements of the SNCR technology should be taken into consideration 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 operating in parallel, it could 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 not exceed 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 not a major issue. With the temperature controlled activation of individual lances, it is possible to assure that the reaction takes place in the optimum temperature range over 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 sufficient NO_x reduction is possible during any boiler load.

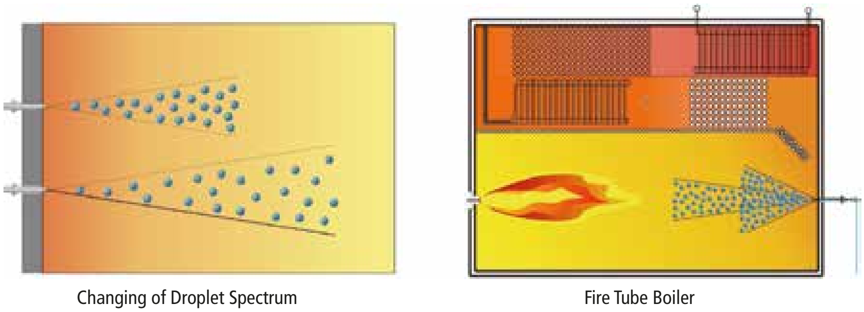


Figure 8: Flue gas cooling by increasing the quantity of cooling water

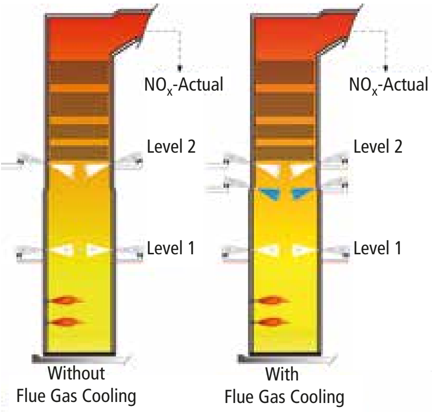
To achieve this, a possible measure would be to increase the quantity of dilution water. (Figure 8). However, this has following disadvantages and is therefore not recommended in most applications:

- Varying quantities of water change the droplet spectrum and consequently the size of the droplets and their penetration depth.
- The concentration of the water-reagent-mixture is also changed so that the area where most of the reduction takes place is not covered with a sufficient quantity of reagent.

A continuous operation of the boilers 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.

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.

In larger boilers where the reagent is always injected 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.



Design Data	
Fuel	Lignite, light distillate
Flue gas flow	173,000 Nm³/h
NO$_x$ without SNCR	400 mg/Nm³
NO$_x$ with SNCR	200 mg/Nm³
NH_3 with SNCR	< 15 mg/Nm³
Flue gas cooling starting at about 80 percent boiler load	

Figure 9: 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.

The plant shown in Figure 9 which is rarely operated 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 about 400 mg/Nm³.

5. Most recent developments of NO$_x$ reduction with SNCR

5.1. 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 10). Depending on the temperature profile individual lances or a group of lances are activated.

Figure 11 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.

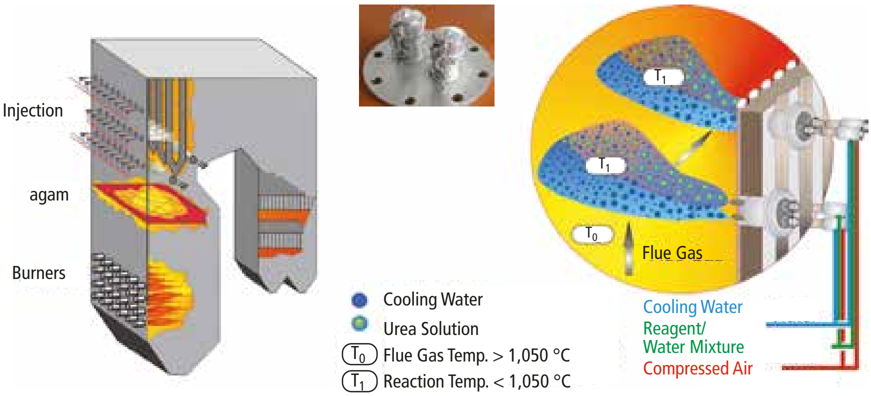


Figure 10: Selective Flue Gas Cooling for coal-fired boilers

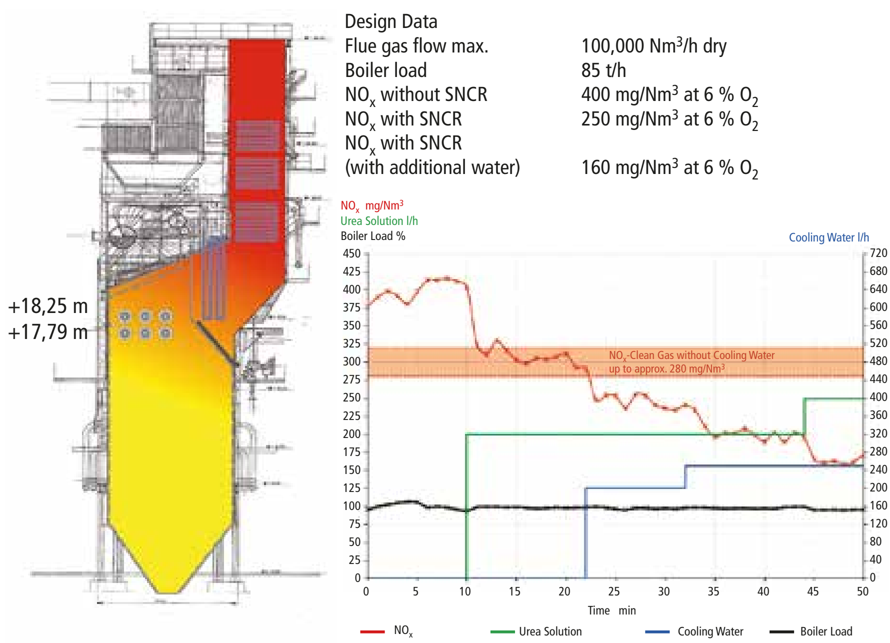


Figure 11: Selective Cooling – Retrofitting of an SNCR plant operated with urea solution

5.2. 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.

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 12).

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.

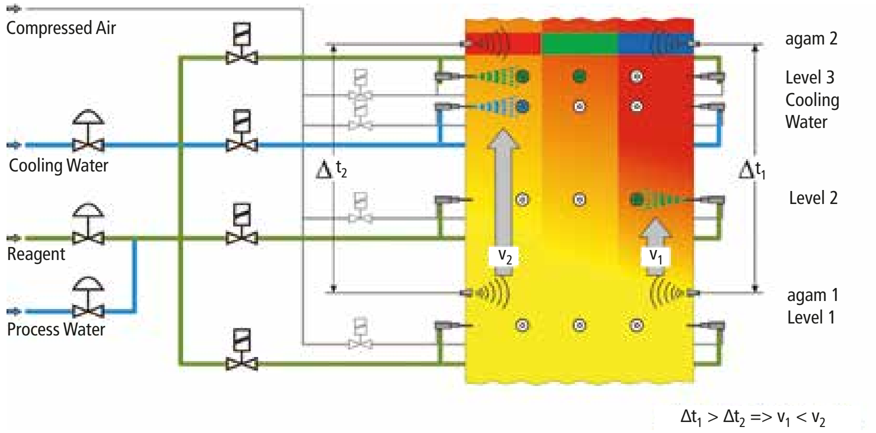


Figure 12: Principle of Adaptive Flue Gas Cooling

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.

5.3. Defining and incorporating of flue gas velocity and NO_x mass flow profile

With the control of injecting the reagents into the flue gas based on temperature measurements only, no further improvements of the performance can be expected. That could only happen if other parameters which influence the operation of the SNCR process are incorporated into the SNCR process.

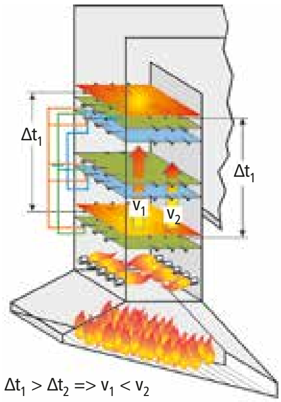
So far, in most SNCR plants the control system is based on the flue gas temperatures, the boiler load, and the NO_x emissions, in some cases also on the NH_3 slip.

During operation of a combustion plant, the NO_x concentration and the flue gas velocities cannot be measured with a reasonable effort. In order to simplify the process calculations it generally is assumed that the velocity of the flue gas and the NO_x concentration are almost homogenous over the whole cross section in the furnace. However, this is by far not the case. NO_x, O_2, CO, flue gas velocity, etc. are forming similar profiles as the temperature distribution.

Since the NO_x to be reduced is the product of

NO_x concentration [mg/Nm³] • flue gas flow [Nm³/h],

flue gas velocities and directions as well as the NO_x concentration at different injection locations or zones are of equal importance for the efficiency of the SNCR process as the temperatures.



Temperature Information is Used for
- Injecting reagents into the optimum temperature window
- Flue gas cooling in areas which are too hot for SNCR
- Controlling the quantity of process water to optimize the penetration depth and the spraying pattern
- Controlling the cooling water
- Controlling ammonia slip
- Derivation of the flue gas temperatures depending on the temperature gradients
- Optimizing the soot blowing cycles

Optimization of
- NO_x reduction
- Ammonia slip
- Consumption of water
- Consumption of reagents

Figure 13: Benefits of temperature information for improved SNCR performance

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.

With the installation of the temperature measurement systems in two levels the temperatures in the levels and sectors can be compared and temperature gradients 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 NO_x reduction and to minimize 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 (Figure 13).

5.4. Process control

For technical reasons, it is not possible in the SNCR process to measure the raw and clean gas NO_x concentrations simultaneously. Since measurements are performed in the colder flue gas downstream the boiler, the NO_x content can only be measured alternately with or without injection of reagent. Since there is a substantial delay in the control cycle – from injection into combustion via NO_x sampling, analysis and measurement in the stack, the newly set concentration of the reagent and from the control valve back to the lances – the reagent quantities need to be roughly calculated in advance in order to respond to changing operating conditions as quickly as possible.

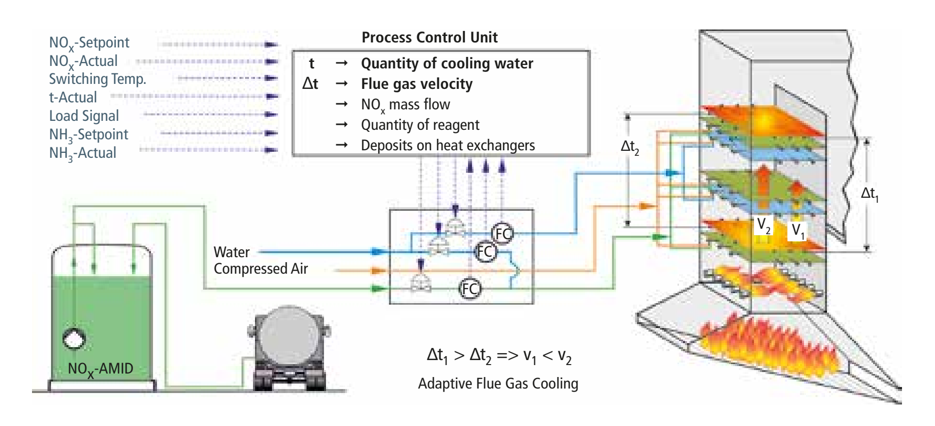


Figure 14: Flow chart of an SNCR with Adaptive Flue Gas Cooling

This is effected by means of a load signal, the set point defined for NO_x clean gas and the resulting NO_x freight. Depending on the actual NO_x clean gas concentration, the quantity is continuously corrected. To avoid extreme variations of the reagent flow, a constant base quantity of reagent is preset to assure the minimum flow of reagent at any time. If higher quantities of reagent are needed with increasing boiler load the control valve will be opened according to actual demand.

Depending on the flue gas temperatures as measured, and depending on other operating data the injection levels, respectively individual injectors, are changed as appropriate. Mostly a stand-alone PLC controls the process when the SNCR is installed in an existing plant (Figure 14). For new plants, the process control system of the overall plant is often used. Visualization is effected by means of a bus connection between the SNCR and the control room.

There are studies in progress to apply process controls based on computerized calculations like *online CfD*, Fuzzy Logic, Artificial Intelligence or similar technologies. Because of the complexity of the SNCR process, the changing fuels, operating conditions and other influences, need to be developed further.

6. Summary and outlook

The SNCR process has been well established and accepted as Best Available Technology (BAT) for smaller combustion plants like WtE 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 as well.

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 promising results which show further potential for improvements. Currently, there is an increasing demand for coal fired boilers with a capacity > 300 MW_{el}, emission limits < 150 mg/Nm^3 and NH_3 slip < 5 mg/Nm^3.

7. Literature

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