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Advanced SNCR Technology for Power Plants

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1. Introduction

In Western Europe the retrofitting of large coal fired boilers with NO_x control systems has been concluded years ago. Since the selective catalytic reduction process (SCR) was considered to be the best available technology (BAT) in the eighties and nineties, most of the boilers are equipped with SCR now.

Starting in the nineties a number of Eastern European countries joined the EU and as a consequence they also had to accept the emission limits which are in force. This means for most of the power plants that the existing boilers either have to be shut down or measures have to be taken to follow the stringent regulations to control emissions like NO_x.

For the SCR-technology, many reliable results and experiences are available to estimate the feasibility as well as investment and operating costs with high accuracy. However, apart from the fact that the investment costs for an SCR are about ten times as high as for an SNCR-system other effects also have to be considered.

- Installation of the catalyst is often critical, especially when the boiler has a large economizer instead of an air preheater so that heat exchangers would have to be replaced to accommodate the catalyst.
- Due to the height of most boilers, accommodation of the weight of the catalyst and the steel structure would generally cause static problems.
- Pressure drop within the catalyst would result in higher electrical consumption and operating cost for SCR.
- The investment volume would amount to the multiple of the cost of an SCNR-system.
- The downtime of the boiler for retrofitting with SCR could cause a considerable loss of profit.

Especially during the last years, the SNCR-process has been continuously improved for small and medium sized boilers like waste incineration plants, and is widely considered now as the ‘Best Available Technology’ (BAT) for this type of boilers. With this in mind an increasing number of owners of power plants are seriously investigating today if the SNCR-process is feasible for their large boilers as well. Besides the performance, special attention is generally being paid to the overall cost compared to SCR.

This paper describes that the SNCR-process is an attractive alternative for large boilers as well if the results and experiences which are gathered to date are applied and developed further to meet the demands of the owners of larger boilers.

2. Major NO_x-Control Technologies

NO_x-control technologies can be classified into two categories:

- Primary measures: combustion NO_x-control technologies
- Secondary measures: post-combustion NO_x-control technologies

2.1. Combustion NO_x-Control Technologies

The objective of combustion control technologies is to minimize the formation of NO_x when the combustion is taking place. This can be achieved by reducing the oxygen and decreasing the temperature in the primary combustion zone so that not completely burnt carbon compounds (CnHm radicals, CO, residual coke) are available in enriched form which have a reducing effect on already formed NO.

In the secondary combustion zone, the combustion will be completed by addition of air. In order to get optimum results, i. e. low NO and maximum burn out, a long residence time in the reducing atmosphere of the primary combustion zone and a good mixture with the combustion air in the secondary combustion zone are essential. In order to comply with the requirements for low NO_x-combustion, following measures are taken alone or in combination with each other:

- Adjustment and optimization of burners and combustion air
- Reduction of excess air
- Air staging in the combustion zone
- Air staging in the burners
- Fuel staging
- Flue gas recirculation

The effectiveness of such primary measures depends very much on the boiler design and the characteristics of the fuel. Each individual case has to be studied carefully with regard to

- Stability of the flame
- Corrosion of the furnace
- Burn out of the fuel
- Fuel range
- NO_x-reduction
- Efficiency of the boilers and cost.

In practical applications, compromises have to be found between the technical possibilities and the effects on cost and operation.

2.2. Post-Combustion NO_x-Control Technologies

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.

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**) which is called the temperature window and with catalyst between 160 °C and 350 °C.

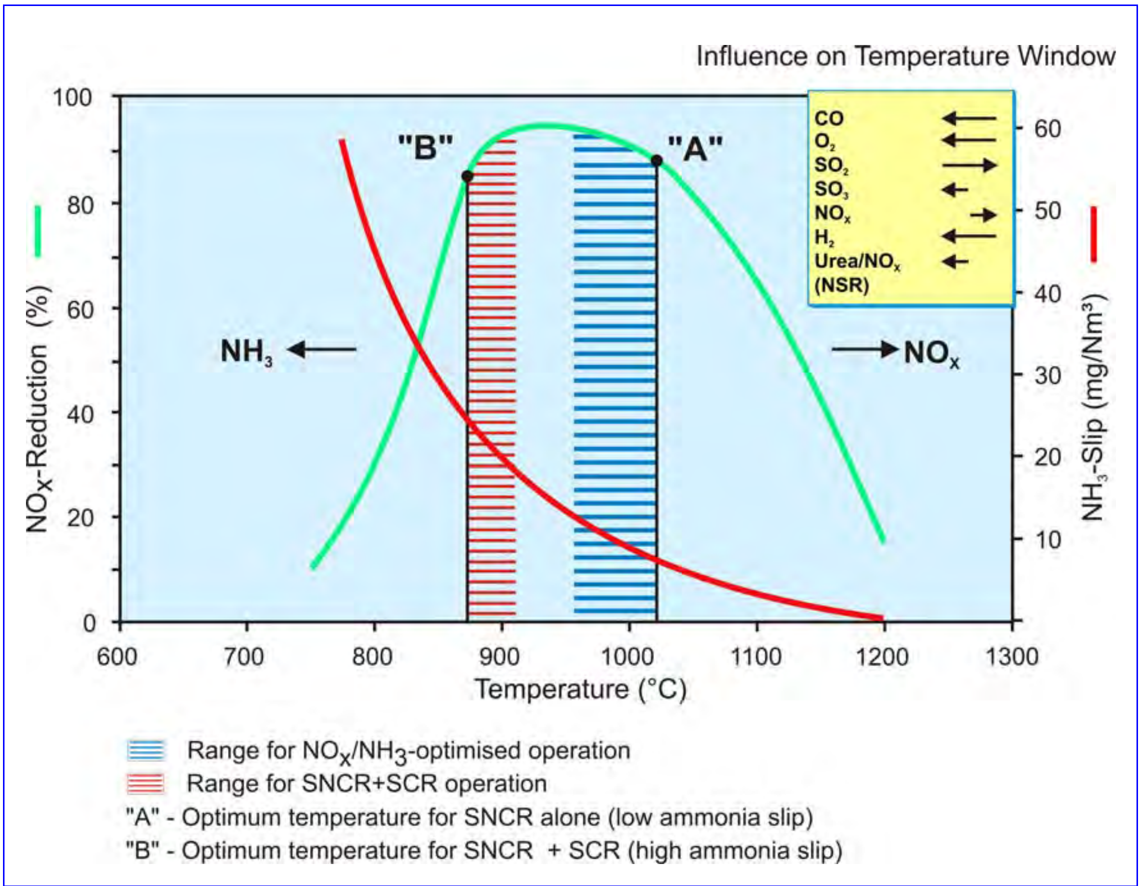

Fig. 1: NO_x-Reduction as a Function of Temperature

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 $NH_2CONH_2 + 2\ NO + ½\ O_2 \rightarrow 2\ N_2 + CO_2 + 2\ H_2O$

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 NH3-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.

3.1. Concept for Plants Designed for Moderate NO_x-Reduction

The simplified process flow scheme (**Figure 2**) shows the function and the scope of equipment of a typical SNCR-system for urea solution as installed in numerous grate fired plants with various fuels, such as municipal waste, bio mass, RDF, coal, etc., which are operated according to the current regulations with NO_x-reduction rates of up to 50 to 60 %. Subject to the specific requirements, these plants are generally equipped with one or two injection levels, which can be operated alternatively depending on the boiler load and/or the flue gas temperature.

With this concept, NO_x values of 120 to 150 mg/Nm³ and an NH_3 slip of 10 to 15 mg/Nm³ can be maintained if the injection lances are arranged in such a way that a wide temperature window for the injection is covered. Temperature variations and imbalances, which cause insufficient reduction in one area, are compensated for by higher reduction rates in another area. To follow larger variations and imbalances in temperatures during operation, two injection levels - which can be operated alternatively depending on the mean temperature measured at the end of the furnace - have proven to be successful.

Under favorable operating conditions as can be found when homogeneous fuels are burnt at constant loads, even NO_x clean gas values below

100 mg/Nm³ can be obtained with this configuration while the NH_3 slip still remains moderate.

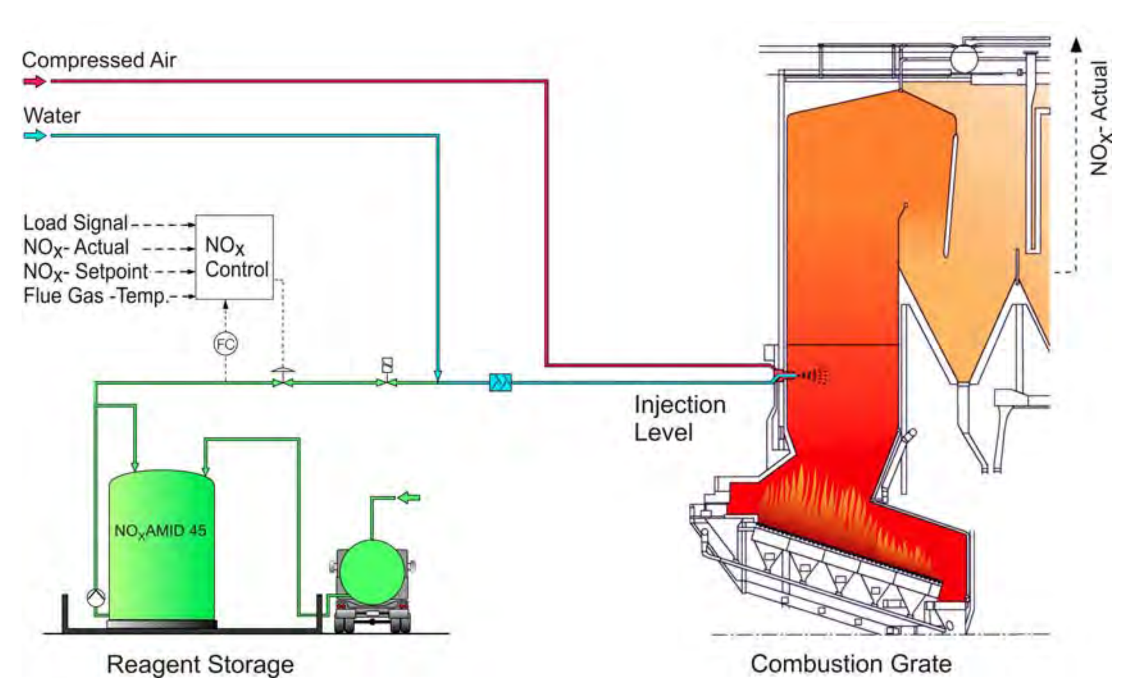

Fig. 2: Process Flow Scheme of an SNCR with Urea Solution for an MSW

3.2. Temperature Measurements

To get a feeling whether the SNCR-process could be suited for existing boilers, as a first step realistic temperatures need to be obtained at possible positions for the injection of the reagent. The thermocouples measuring the temperatures are usually installed at the boiler walls and are therefore affected by radiation of flames and boiler walls. For this reason, a suction pyrometer will generally be used. It consists of a water-cooled lance with a thermocouple (Ni-CrNi) on its tip. The thermocouple is protected against radiation with a ceramic shield. The hot flue gases are sucked into the lance in such a way that the real gas temperature can be measured. The negative pressure required is generated by an ejector with compressed air.

3.3. Test at Approx. 200 MW_{el} Coal-Fired Boiler in Germany and Poland

To obtain more reliable information whether the required NO_x-reduction could be achieved with the SNCR-process, it is recommendable to perform simple tests with a portable test installation. These tests give valuable information which efforts need to be made with regard to the design and the equipment of the commercial SNCR plant and which performance can be expected and guaranteed under varying operating conditions.

In order to keep the technical efforts and the cost of tests as low as possible, technical shortcomings of the existing demonstration plant are accepted. The typical test equipment consists of a pumping module and a mixing and metering module with exits to the injectors, flow meters and all necessary armatures **(Figures 3 and 4)**. The variation of reagent, water and compressed air is usually adjusted manually.

The preparation of the boilers is usually limited to the minimum necessary. For instance, the time and cost consuming bending of tubes in the boiler walls for accommodating the injection lances is generally avoided. If possible, existing openings are used for the injectors.

Nevertheless, the test results usually provide sufficient information to decide whether the required performance for a commercial plant can be met with SNCR.

Fig. 3: Demonstration Plant: Pumping Module, NO_xAMID Container

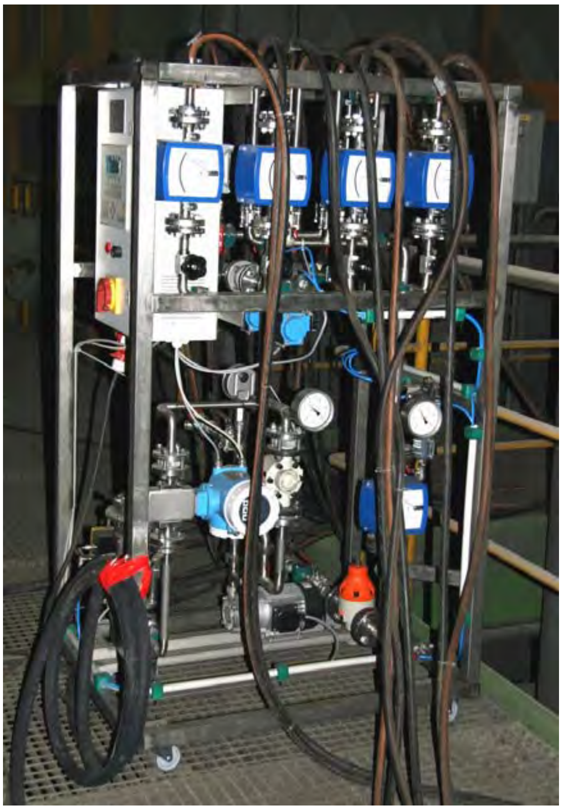

Fig. 4: Demonstration Plant: Mixing and Metering Module

Regardless of whether urea or ammonia water will be used for the commercial plant later on, the tests are mostly performed with urea solution. The reason is that urea solution is much easier to handle than ammonia water. Therefore, it does not make much sense to use ammonia water for the short duration of the tests. From the performance point of view, both reagents are comparable for most applications, so that the test results provide reliable information for a commercial plant regardless whether urea solution or ammonia water will be used later on. Tests have been conducted in several boilers with a capacity up to 225 MW_{el} in Germany, the Czech Republic and Poland.

In principle, a test-system is designed similarly to a commercial system, but an SNCR plant which is specially designed for the respective application should have a better performance for the following reasons:

- Equipped with an automatic control system, the SNCR-system can respond faster to changing operating conditions than a manual switching of the lances can do, thus also obtaining better results.
- Openings for the injection lances are inserted into the boiler at optimum positions so that a homogenous distribution of the reagent is achieved.
- Automatic control of the injection lances based on acoustic temperature measurements ensures for each lance that the reagent is injected in the optimum temperature range.

Boiler Data

Commissioning	1982
Gross Capacity	200 MW
Net Capacity	185 MW
Flue Gas	545.000 Nm³/h
Main Steam Flow	576 t/h
Fuel	Ballast Coal
NO_x - Baseline	≈ 330 mg/Nm³
NO_x - with SNCR	< 200 mg/Nm³

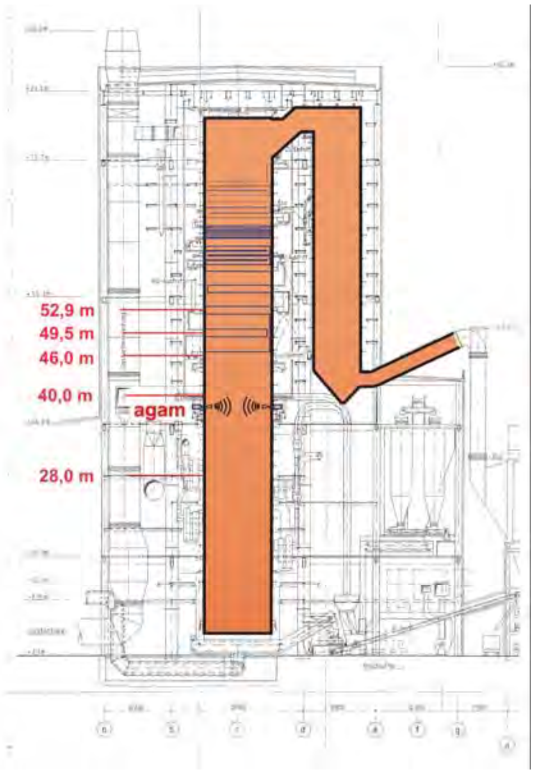

Fig. 5: SNCR Process for a Coal-Fired Boiler in Germany

To generate reliable data for a decision whether SCR or SNCR is preferable, the feasibility of retrofitting the plant in Germany with an SCR-system has been estimated thoroughly before the trials with SNCR had started. For this specific application (**Figure 5**) and for most other boilers the results can be summarized as follows:

- The investment costs for an SCR-system are about ten times higher than those of an SNCR-system.
- Despite the more efficient use of the reagent, the operating cost of a (High Dust) SCR would be significantly higher, especially due to the pressure loss in the catalyst.

- In most cases, the installed blower capacity is not sufficient to compensate for the additional pressure loss within the catalyst.
- In an induced draught system it may be necessary to reinforce the flue gas ducts on the suction side due to the decreasing pressure.
- The SO_2/SO_3 conversion in the catalyst can cause corrosion, when the temperature falls below the dew point of sulphuric acid.
- The retrofitting would be very time consuming and at the same time interfere considerably with the plant's normal operation.
- The availability of the SNCR-system is practically unlimited, as all main components are redundant and can be exchanged during regular operation.
- In plants using SCR many operating hours are lost when catalysts are exchanged or regenerated.

Considering all relevant aspects like the degree of NO_x-reduction, cost-benefit-ratio and availability, a utility company in Germany chose the SCNR-system for commercial use, after the tests had been completed successfully. This commercial plant is in operation since 2010.

3.4. Combustion Chamber Diagnosis with the agam System

The temperature measurements with suction pyrometers performed in a 200 MW_{el} coal-fired boiler and the readings from the permanently installed thermocouples only permit a rough estimate regarding the temperature profiles in the individual potential injection levels during the respective boiler loads. Furthermore, the temperature distribution and imbalances resulting from the boiler load, the ignition behavior, the burner configuration, etc. may vary strongly.

Due to an increasing layer of deposits on the heating surfaces during operation, temperature in the furnace increases and the temperature window moves further upwards, respectively downstream in the combustion chamber. Depending on the fuel type, fuel distribution and air supply, temperature imbalances of up to 150 °C - sometimes even higher - are typical. The flue gas temperatures measured with thermocouples and averaged, as typical in MSW plants, can be used as reference temperatures to a limited extent only, as these average temperatures do not tell anything about the temperature profile or the imbalances within the injection levels. Furthermore, radiation from the furnace walls affects the measurements, resulting in deviations from real flue gas temperatures of 60 to 100 K. In addition, deposits on thermocouples lead to an increasing insulation effect during operation of the boiler plant. Therefore, temperature measurements of the process control system are time-delayed in a range of 10 minutes and longer, depending on the thickness of such deposits.

To ensure that the reagent is always injected in the upper range of the temperature window under any operating condition, i.e. in the range where NO_x-reduction is highest and NH_3 slip is lowest, acoustic gas temperature measurement systems (agam) are provided in plants where high performance is required. Agam measures the real gas and determines the temperature profiles across the entire combustion chamber cross-section.

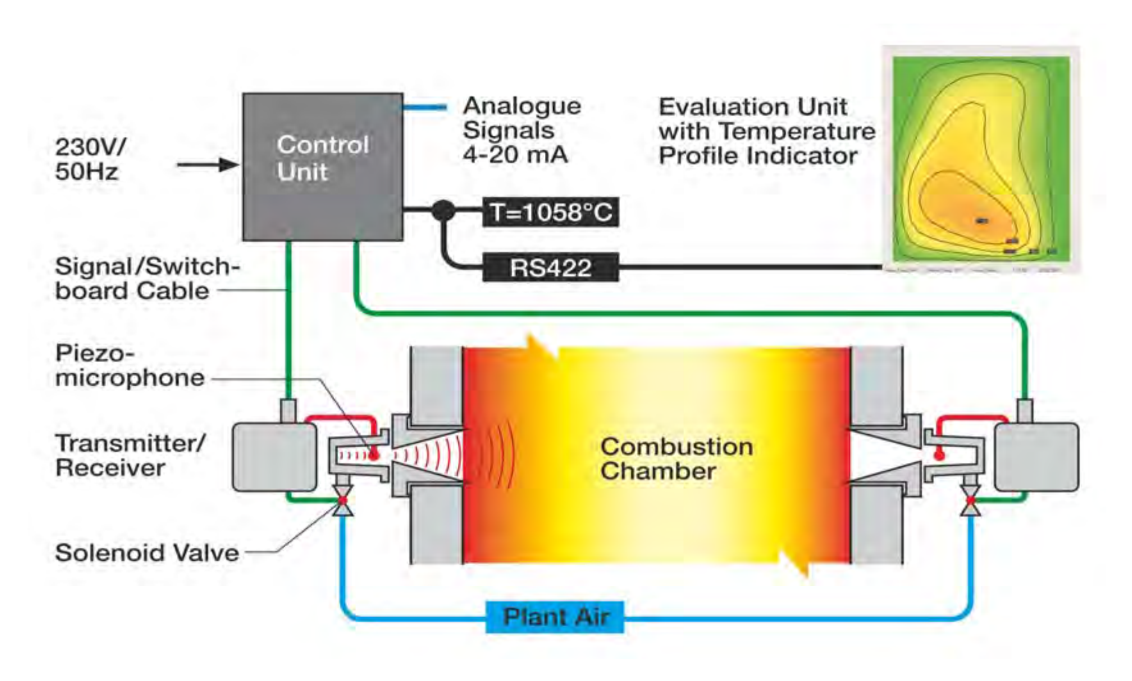

Fig. 6: Basic Configuration of Acoustic Gas Temperatures Measurement System (agam)

The system consists of transmitter and receiver units of an identical mechanical and electrical design mounted to the walls of the combustion chamber and an external control unit **(Figures 6 and 7)**.

During the measurement the solenoid valve in the compressed air line on the transmitter side is opened, generating acoustic signals. The signals are recorded simultaneously on both the transmitter and the receiver sides.

The digitalized signals are used to measure the transmission time. As the distance is known, the velocity of sound can be determined, which is then converted into a temperature, i.e. the so-called path temperature. With several combined transmitter/receiver units acting on one level, multiple path configurations are obtained to calculate the two-dimensional temperature distribution in one level immediately and without delay.

The temperature profile is divided into sections and can be assigned to individual lances or groups of lances to switch them to another level depending on the flue gas temperature measured. This ensures that the reagent gets to the locations, which are most effective for the reaction even at rapidly varying flue gas temperatures, and the SNCR plant is always operated in the optimum temperature range with regard to the degree of NO_x-reduction, NH_3 slip and reagent consumption **(Figure 8)**.

Fig. 7: SNCR Injection Lances with agam

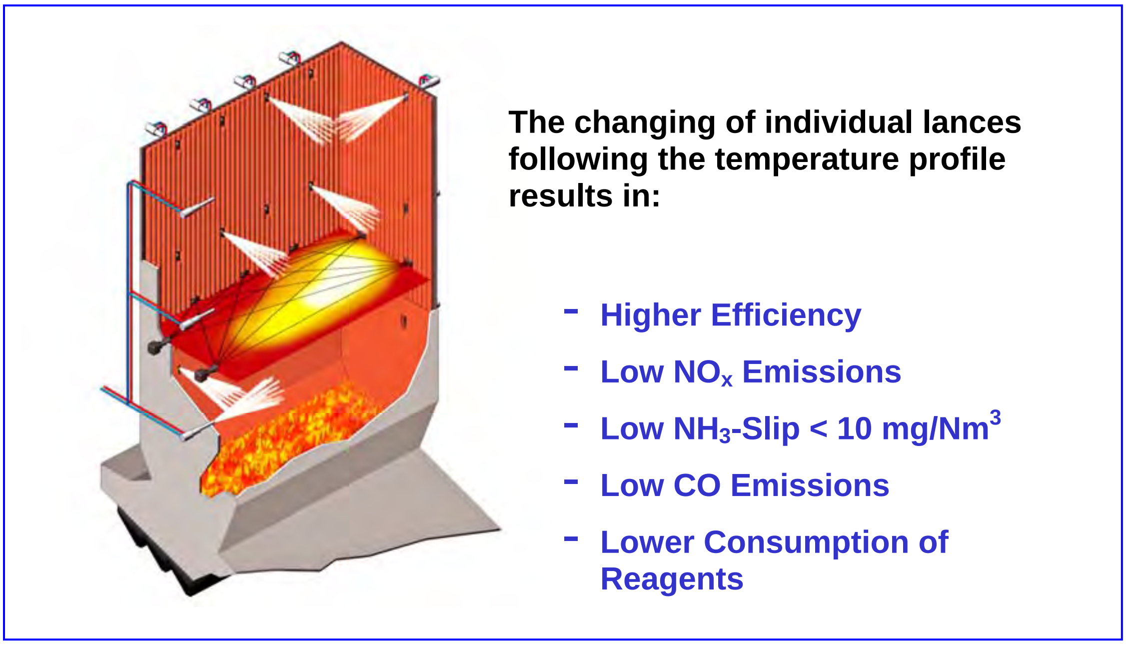

Fig. 8: Changing of Individual Lances Depending on Flue Gas Temperature

After the basic decision had been taken in favor of the SNCR-process, a preliminary acoustic gas measurement system (agam) was installed even before the final contract was awarded. The intention was to obtain as much detailed information as possible and to allow for a maximum certainty in designing the commercial SNCR plant - in particular regarding the configuration and confirmation of the SNCR injection levels and the number and positions of the injectors for the reagent.

The temperature measurements were performed at the end of the combustion chamber (39 m) with different loads and configurations of pulverizers. The positions of the agam measurement level and the burner levels are shown in **Figure 9**. It also shows the arrangement of the 8 transmitter and receiver units as well as the paths of the acoustic measurement. On the basis of the 24 path values measured, the temperature distribution (isotherms) is calculated tomographically.

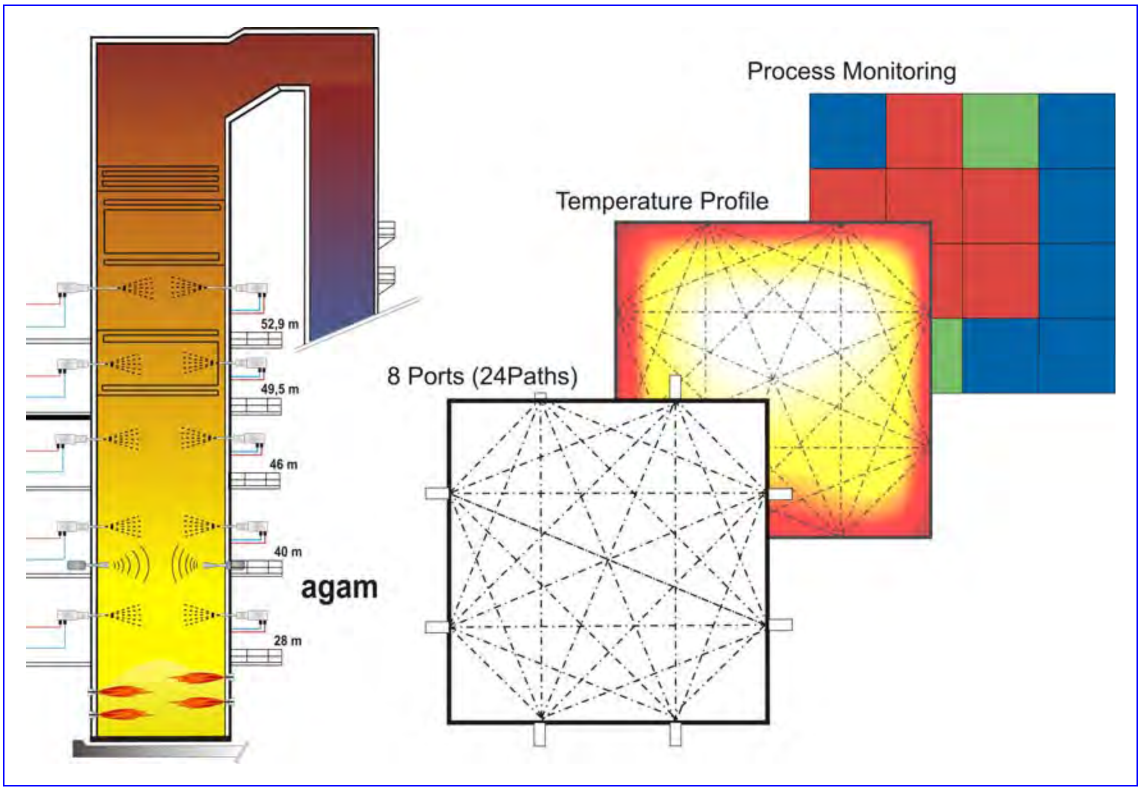

Fig. 9: Boiler with Five Injection Levels and agam

Four symmetric zone temperatures are determined from the temperature matrix. The surface average value is used to calculate deviations for the zones. The monitor of the acoustic diagnostic computer displays the isotherms, the configuration of the 16 zones with indication of the deviations from the average value as well as the zone or surface average value **(Figure 10)**. The color in the zones changes from green to red or blue when the deviation from the average value exceeds +25 K or –25 K. Under the zone or isotherm diagram the four zone deviations from the average value are shown as trends.

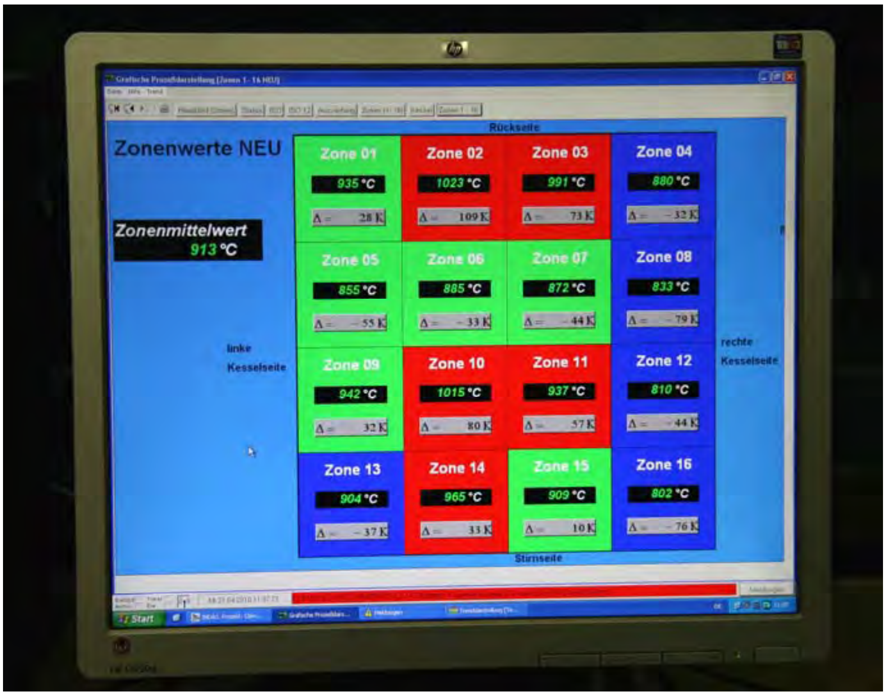

Fig. 10: agam - Configuration of 16 Temperature Zones

The average temperature at the end of the combustion chamber varies between about 750 °C at low load (45 MW_{el}, burner level 1) and 1,155 °C at full load (185 MW_{el}, with all burners in operation)

The final engineering concept was decided on the basis of the analyses of temperature measurements and the tests with the SNCR demonstration plant for a 200 MW_{el} coal-fired plant. **(Figure 11)**

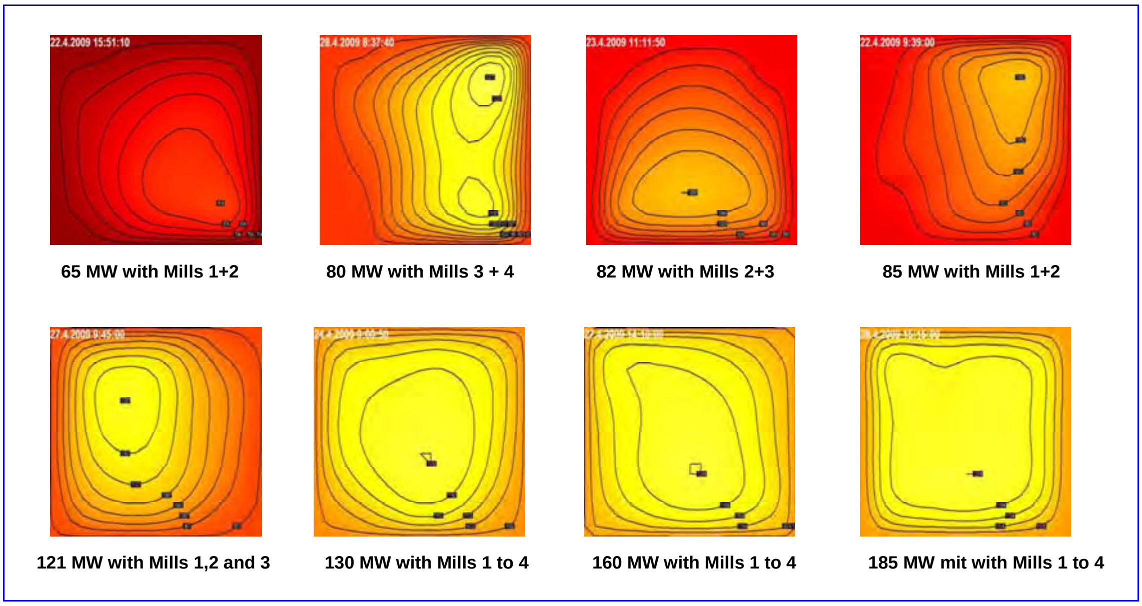

Fig. 11: Temperature Profiles in agam Measurement Level at Different Boiler Loads and Configuration of Mills

4. Technical Concept of the SNCR Plant for a 200 MW_{el} Coal-Fired Boiler

The simplified process flow chart **(Figure 12)** shows the function and the scope of supply of the commercial SNCR plant as designed, installed and commissioned in the power plant. Due to the significant temperature differences between low load (20 %) and full load as well as the extreme temperature imbalances, five injection levels are installed between 26 and 51.8 m. The injectors are arranged in such a way that the right and the left sides of the boiler can be controlled independently from each other. Each injection lance can be individually activated or deactivated.

The SNCR plant in its final stage mainly consists of the key components described below. Compared to a plant operated with urea solution, a more sophisticated design is needed for the operation with ammonia water since safety requirements are more stringent.

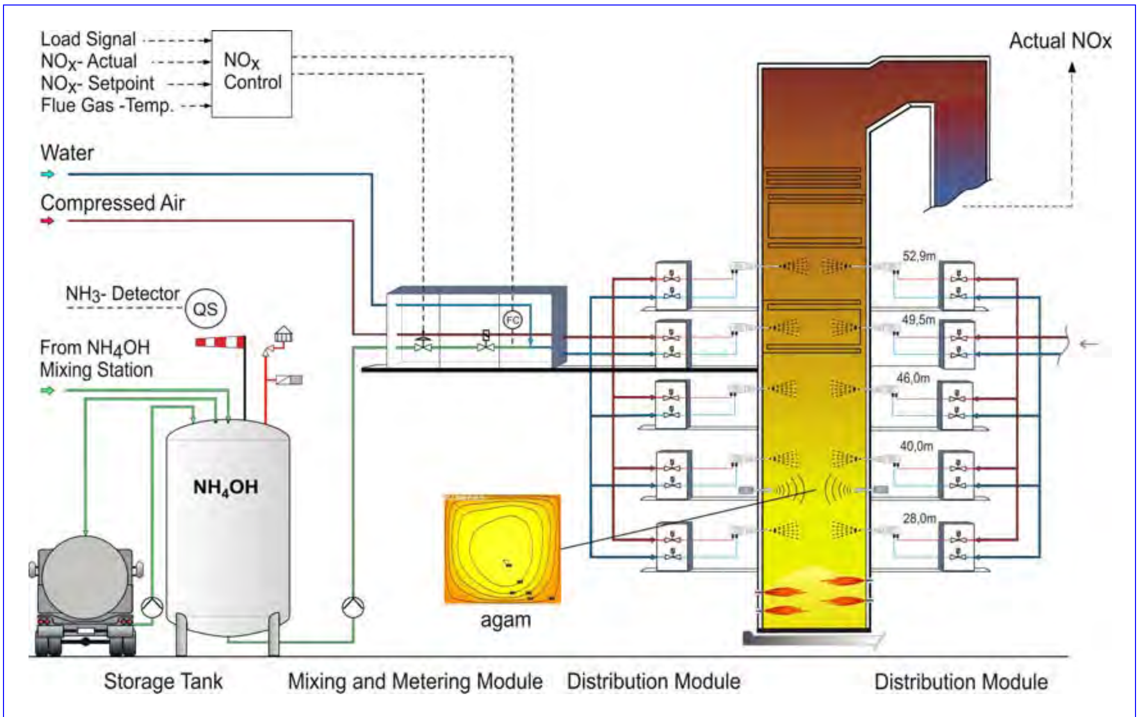

Fig. 12: Flow Diagram of SNCR with Five Injection Levels and agam

4.1. Reagent Storage and Supply

Ammonia water which is used as reagent is filled into the storage tank of stainless steel from a mixing station. Alternatively, filling from tank trucks is possible. Ammonia vapors are absorbed in a tank filled with water and returned into the storage tank when a certain concentration of ammonia is reached. Therefore, a gas exchange pipe is only required **(Figures 13 and 14)** for filling from tank trucks.

The comprehensive safety equipment includes, amongst others, ammonia sensors, flame arresters, full-body and eye showers, wind direction indicators.

Ammonia water is classified as a substance of class 2 water hazard (dangerous to water) and, in addition, falls under the European standard EN 12952-14:2004 (formerly TRD 451 and 452) due to its high environmental hazard potential. When handling ammonia water, special attention must be paid to

- Ammonia water in the tank and pipes
- Gaseous ammonia after vaporization above the liquid in the tank
- Gaseous ammonia in case of leakage.

Fig.13: Storage Tank for Ammonia Water with Pumping Station

Fig. 14: Storage Tank for Urea Solution (NOxAMID)

The special hazard potentials of both dissolved and gaseous ammonia need to be considered.

4.2. Transfer Pumps

From the storage tank, the reagents are directly pumped back into the tank via a recirculation line and a pressure relief valve. A pipeline branches from this circulation line and leads to the two mixing and metering modules. Control valves supply the quantity of reagent required for denitrification, whereas the excess ammonia water is returned to the tank. The less costly submersible pumps are not permitted for conveying ammonia water from the tank to the injection lances. For the SNCR plant leak-free magnetic coupled pumps are used. The inside of the tank is considered to be explosion protected. Insulation and heating of the tank and pipes are not required since the ammonia content lowers the freezing point of water and crystallization of ammonia is not possible. The freezing point of ammonia water (25 %), for instance, is – 57 °C.

4.3. Mixing and Metering Modules

The mixing and metering modules mainly serve to:

- Measure all flow rates (reagent, water, air)
- Mix the reagent with process water
- Stop the reagent supply in case of operating trouble.

Because of the number of injection levels and injectors, two distribution modules were installed on each of the five injection levels to distribute the liquids and the atomizing air to the injection lances. All modules contain the necessary armatures as well as measuring and control instruments for flow rates and pressures of the reagents, the compressed air and the process water **(Figures 15 and 16)**.

Fig. 15: Mixing and Metering Module

Fig. 16: Distribution Module

The pressure of the liquids and the compressed air depend on the required penetration into the boiler and the droplet size. They usually range from 3.5 to 4 bar at the inlet of the injection lances. Considering the pressure loss inside the module and the pipes to the lances, the pressures at the inlet of the mixing and metering module range from 4.0 to 4.5 bar.

All components of the modules are mounted on a base frame. To protect the instruments, in particular against dust and splashing water, the module is housed in a cabinet. Glass doors are provided to make it easier to take readings, also when just passing by. Especially in plants operated with ammonia water, glass doors help minimize the hazard potential since any leak can be identified without opening the doors so that harming people by toxic vapors will be prevented.

Regulations regarding mixing and metering modules operated with ammonia water are more stringent than those applying to urea solution. As a minimum requirement, pipes and fittings must be provided with the pressure rating PN10. For all fittings and materials, 3.1. certificates are required.

To prevent hazards from leakage, ammonia detectors are provided, triggering an alarm at 400 ppm ammonia and switching off the pumps at 800 ppm.

4.4. Injection System

To ensure optimum NO_x-reduction, nozzles are used which are specifically designed to generate the size and the velocity of the droplets for the respective boiler geometry and the flue gas conditions. Each injection lance is provided with one or more nozzles to ensure an even distribution of the reagent/water mixture in the flue gas. For the ease of handling, compressed air instead of steam is used as a driving agent in the German power plant. However, both agents are suited from the process point of view. For the urea containing reagent NO_xAMID, normal process water can be used as dilution water serving as the carrier medium. Since NO_xAMID contains special additives preventing the precipitation of lime, soft water is not necessary. However, demineralized water or deionized water is essential for ammonia water since, otherwise, lime deposits may cause fittings and nozzles to get clogged, sometimes just within one day.

The ammonia water/demineralized water mixture is injected by means of wall lances, in order to avoid the wear of lances by corrosion due to the hot and aggressive flue gases.

4.5. 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 of the boiler, the NO_x content can only be measured alteratingly 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.

This is effected by means of a load signal, the set point defined for NO_x clean gas and the resulting NO_x load. 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 volume is preselected depending on the expected mode of operation. More reagent will be added depending on the demand of the control system.

Depending on the combustion chamber's temperatures as measured by the agam system, and depending on other operating data the injection levels, respectively individual injectors, are changed as appropriate. A stand-alone PLC controls the process. Alternatively, the process control system of the overall plant can be used. Visualization is effected by a bus connection with the control room as is common state of the art, in particular, for larger combustion plants.

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.

5. Performance of a Commercial SNCR in a 200 MW_{el} Coal-Fired Plant

The SNCR plant was put into operation in March 2010. The guaranteed NO_x and NH_3 clean gas values were instantly reached in most cases with boiler loads ranging from 20 to 100 %.

The subsequent optimization phase was very time consuming because for each of the five injecting levels the temperature profile had to be measured at various loads with suction pyrometers, in order to calculate the difference to the temperatures measured with the acoustic temperature measuring system (agam) in level 39 m.

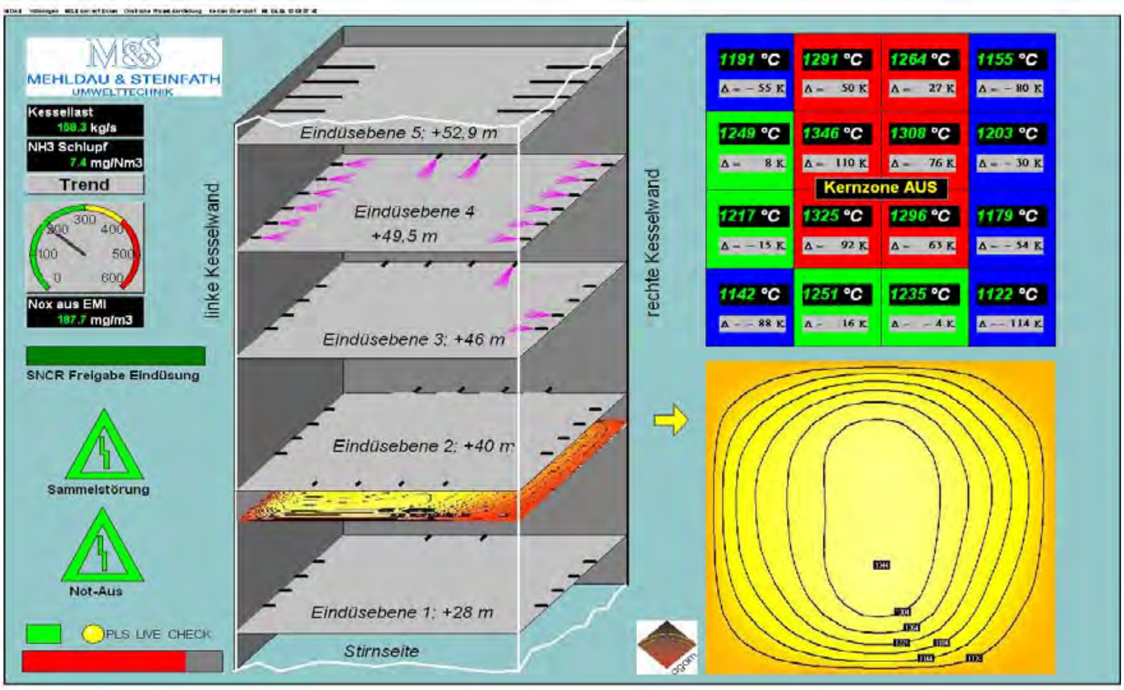

Fig. 17: Display of Temperature Profile, Average Temperature in Zones, Injectors in Operation

This was necessary in order to define which lances should be operated depending on the average temperatures in the zones and at which temperature the switching should be effected at the respective load. Besides this, the settings of pressures and flow rates of (the fluids) ammonia water, demineralized water and compressed air, had to be adapted according to operating conditions.

The operating principle of an SNCR following the temperature profiles and average temperature in the zones established with the acoustic temperature measuring system (agam) illustrated on the display of the control system **(Figure 17)**. The quick reaction after injection of ammonia water and the degree of NO_x-reduction can be seen on **Figure 18**.

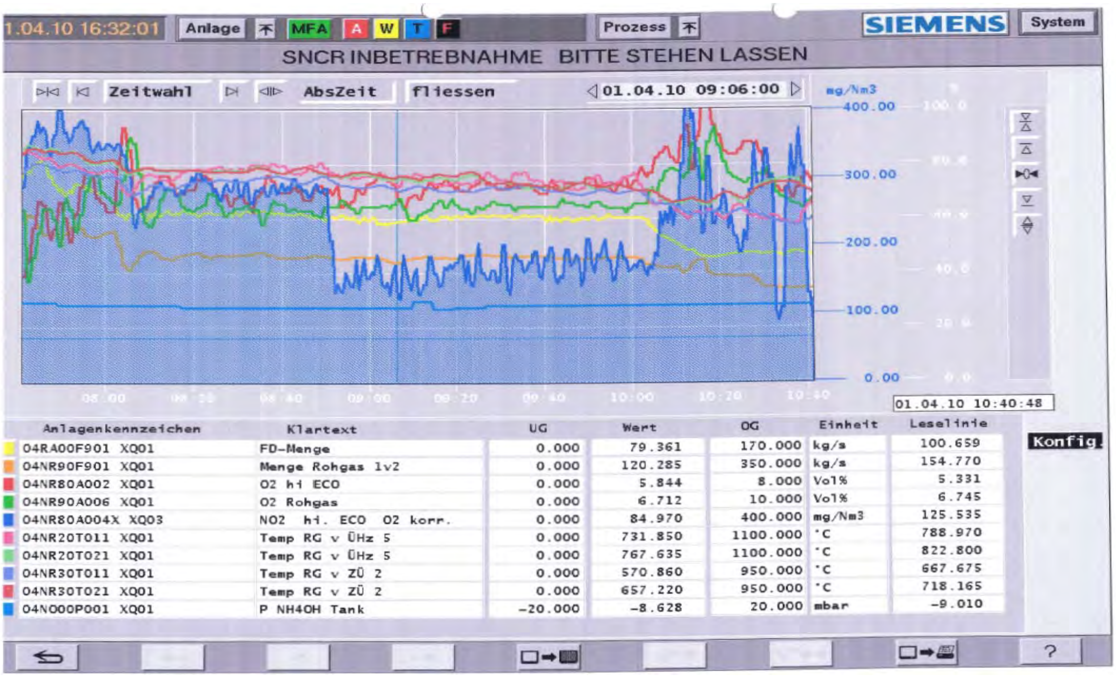

Fig. 18: Results of NO_x-Reduction

6. SNCR-Demonstration in a Coal Fired Plant in Poland

In a power plant in Poland, five coal fired boilers with a capacity of 225 MW_{el} each have been installed. The objective of the demonstration with SNCR was to provide reliable information that NO_x-reductions of min. 25 % can be achieved safely at any boiler load between 40 and 100 % (**Figure 19**).

Temperature measurements which could only be conducted at two openings at 47.4 m showed that there are temperature imbalances of more than 120 K between the measuring points. Further measurements were not possible, since there were no more openings large enough for accommodating the pyrometer lance. During the tests, the urea was injected through openings at levels 37.9 m and 47.4 m from the front wall as well as from the side walls at 47.4 m **(Figure 20)**.

Design Data

Capacity	[MW]	**225**
Flue gas flow rate STP	[m³/h]	**625.000**
SO_2	[mg/Nm³]	**800 - 2.000**
NOx @ 6% O_2 without SNCR	[mg/Nm³]	**250**
NOx @ 6% O_2 with SNCR	[mg/Nm³]	**190**

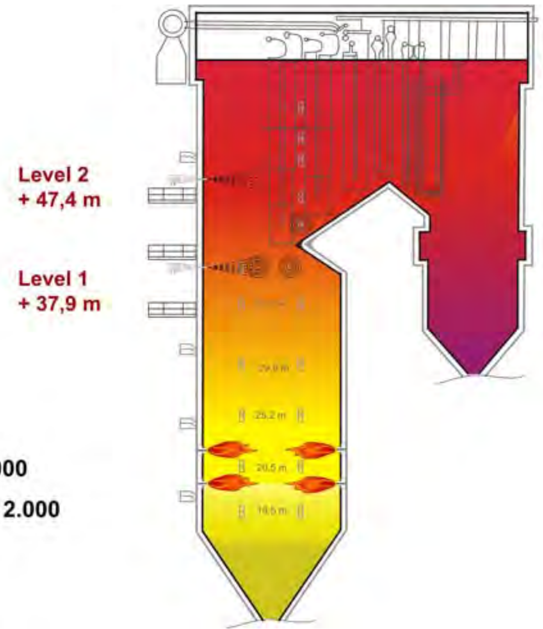

Fig. 19: Design Data of a Coal-Fired Boiler in Poland

Despite of these difficulties, the results were very positive. The required NO_x-reduction of 25 % was exceeded considerably at all loads **(Table 1)** and reached almost 60 % at 75 % load.

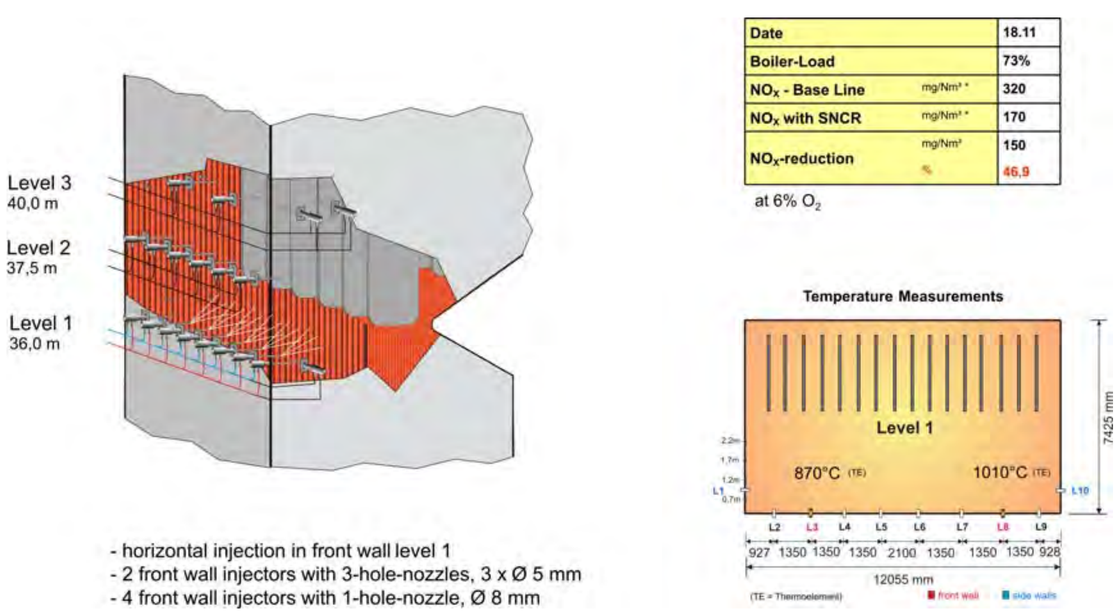

Fig. 20: Operating Results of the SNCR-Plant with a Coal-Fired Boiler

In a commercial plant a third level for injecting the reagent would improve the performance, especially with regard to efficiency and ammonia slip. To keep the ammonia slip low, a small catalyst at the end of the boiler is considered. However, with an acoustic temperature measurement system (agam), similar to the one installed in the German boiler, the reagent could be injected more precisely into the optimum temperatures. As a result the slip could be maintained low enough to keep the ammonia concentration in the fly ash below an acceptable limit so that an additional catalyst slice would not be needed. In samples which were taken from the fly ash, the ammonia content analyzed was measured between 40 and 80 mg/kg.

No.	Date	Boiler Load	NO_x Base Line mg/Nm³*	NO_x with SNCR mg/Nm³*	NO_x Reduction mg/Nm³	%
1	08.10.2009	100 %	197,8	125,3	72	36,7
2	16.09.2009	90 %	233,6	137,0	97	41,4
3	06.10.2009	75 %	232,3	97,8	134	57,9
4	07.10.2009	60 %	150,0	75,0	75	50,0
5	18.09.2009	40 %	456,1	244,3	212	46,4

* at 6 % O_2

Table 1: NO_x-Reduction with SNCR Demonstration Plant at Different Boiler Loads

7. Ammonia Slip

NH_3 can form ammonia salts if SO_3 and/or HCl are contained in the flue gas. These salts can have a considerable impact on the operation and availability of the system downstream in the plant, for example in plants with high SO_3 and low dust concentrations, such as heavy oil fired systems. Consideration should also be given to the fact that SCR processes partially involve much bigger problems with such fuels due to high SO_3 and vanadium pentoxide contents. SO_3 reacts with the ammonia slip, also in the catalyst and forms ammonium salts generating deposits together with the fly ash. Moreover, vanadium pentoxide increases the reactivity of the catalyst, increasing the conversion rate of SO_2 to SO_3, which causes the formation of sulphuric acid and the related corrosion problems downstream the catalyst.

Contrary to the widely spread opinion, it is rather seldom that the formation of ammonium salts due to the NH_3 slip from SNCR plants causes technical problems in coal-fired boilers, such as deposits of ammonium hydrogen sulphate in the heat exchangers and resulting pressure losses. Ammonium hydrogen sulphate mainly accumulates in the fly ash and is separated in the filter. If the plant concept is appropriate, even the loading of the fly ash and the by-products from flue gas cleaning are kept within acceptable limits. In special cases, a small catalyst disc may be subsequently installed at the boiler end without great effort to limit the NH_3 slip and achieve additional NO_x-reduction.

If a wet scrubber is used for desulphurization of the flue gases all the ammonia slip will be absorbed in the gypsum slurry and washed out on the vacuum filter together with the chlorides, so that the gypsum will not be contaminated with ammonia.

8. Availability of SNCR

The availability of the overall plant is practically not affected by SNCR-systems. Generally, values of 98 or 99 % can be guaranteed. All components critical for its operation, such as pumps which may affect the availability of the plant, are provided redundantly. The injection lances in contact with the flue gas, which need to be regularly checked and serviced as wearing parts, may be conveniently checked during operation and replaced well in time if necessary. In order not to endanger the NO_x half-hourly mean values, individual lances should be replaced one after the other. Used lances may be refurbished by cutting or replacing the protection pipes. Occasionally, also the nozzles need to be replaced.

The installed armatures are usually designed for long term operation and need not be replaced while the plant is running if the SNCR is regularly maintained during scheduled shutdowns of the boiler. However, if unexpected damage occurs, most of the problems, such as replacement of flow meters and manometers, may be corrected during operation. Control valves might be more critical. However, they are provided with a by-pass, such that the relevant flow rates of the reagents can be adjusted manually until the relating control valve is replaced or repaired.

Predictive spare part storage and regular maintenance during scheduled plant shutdowns will practically avoid and/or minimize all problems during operation. If, however, an unscheduled shutdown of the SNCR plant becomes necessary, problems may be corrected within a short period of time, at the same time keeping the daily emission limits.

Lime deposits in the piping system, including armatures and injection lances, can only be avoided if urea solutions with a suitable additive (e.g. NO_xAMID) are used. If the SNCR plant is operated with ammonia water as a reagent, it is essential to use demineralized or deionized water as dilution water. The removal of lime deposits is a very time-consuming procedure and may have a considerable impact on the availability of the whole plant.

The SNCR system in the German power plant is equipped with an automatic data acquisition system to facilitate fault diagnosis and settings via remote data connection. The higher investment costs of such a system will pay off within a short period of time since the expenses of costly visits of service engineers can be avoided.

9. 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 optimum reagent for each application. The availability, logistics and cost of urea compared to ammonia water are certainly valid points. But more often there are reasons from the process point of view which should not be ignored since both reagents have their specific advantages and disadvantages depending on the specific application.

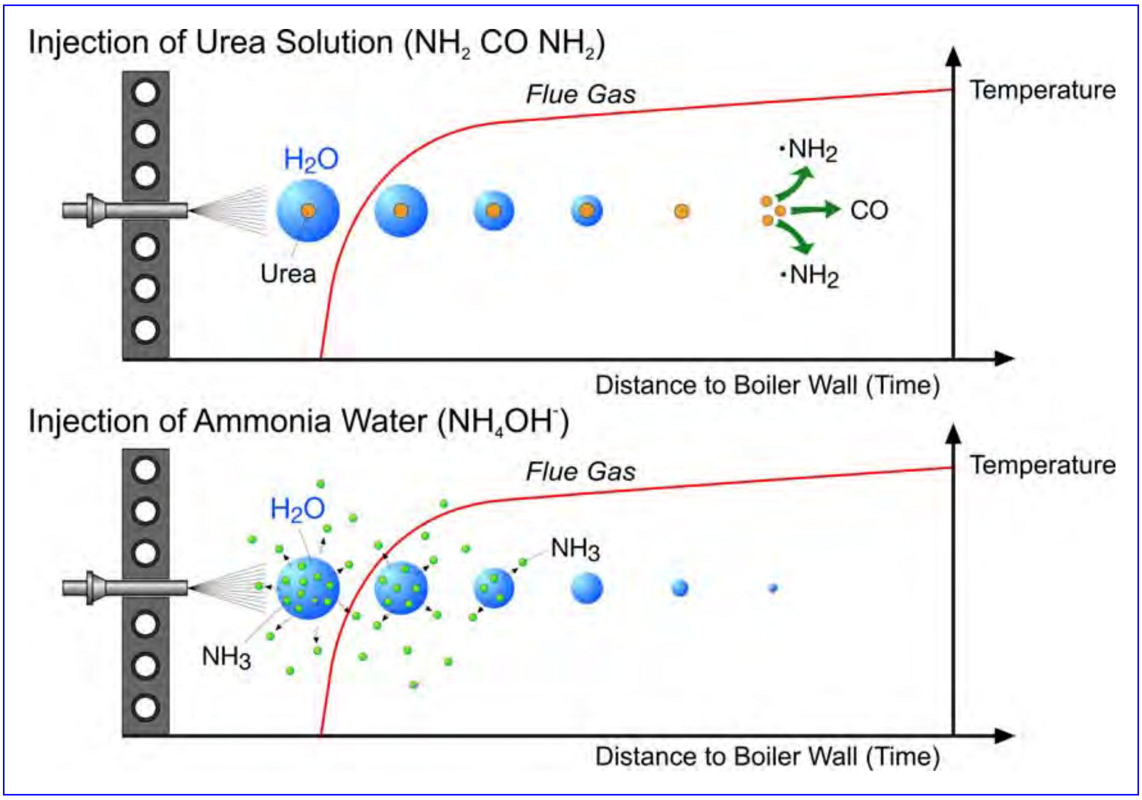

Fig. 21: NO_x-Reduction: Urea versus Ammonia Water

The major difference between ammonia water and urea solution is shown in a strongly simplified diagram in **Figure 21**. 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.

Ammonia is a very highly volatile reagent which is released near the source of the droplet, i. e. the exit of the nozzle, 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 a water droplet. In traditional plants this is accomplished by increasing the steam or air volume 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.

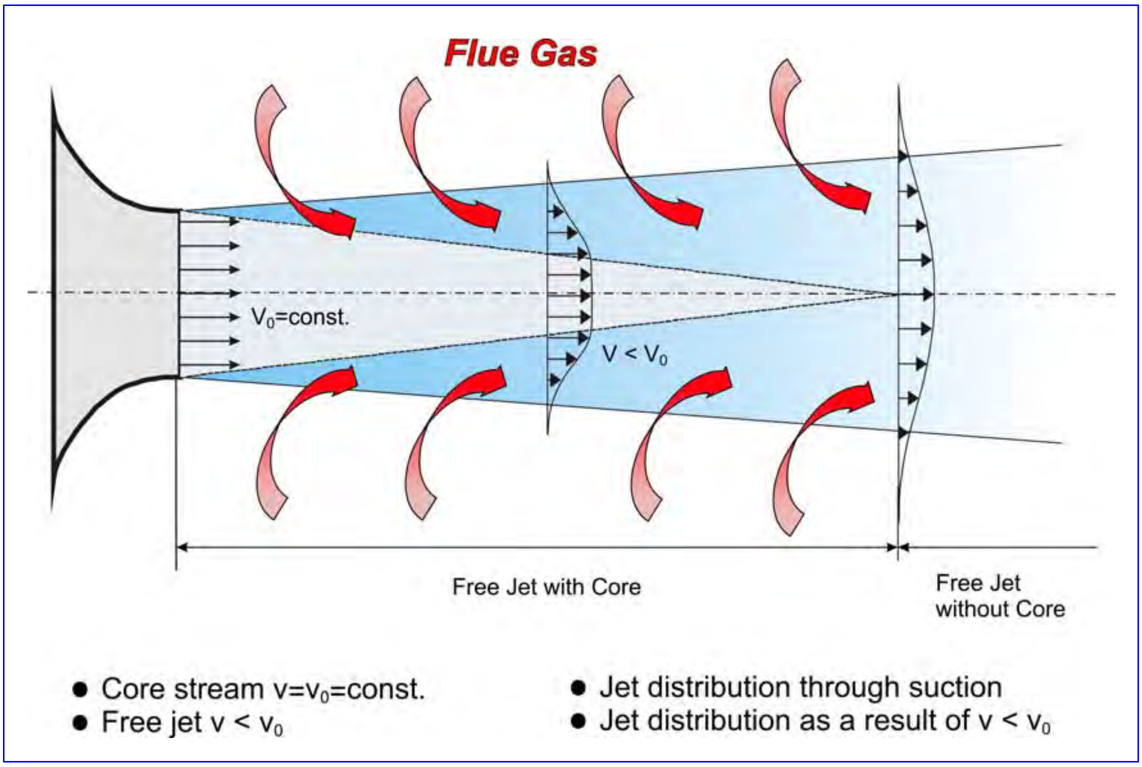

Fig. 22: Mixing Flue Gas with Free Jet

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 22)**. 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 a reagent – especially when the flue gas velocity is low and there are no internal components built in the furnace.

Ammonia is a toxic and easily inflammable gas, easily soluble in water at ambient temperature. With a concentration just under 25 % it is considered to be the optimum fluid for safety and approval reasons. When the temperature increases, ammonia rapidly evaporates from water causing a strong smell.

At 38 °C the partial pressure of ammonia reaches already 1 bar, and therefore stringent safety requirements have to be followed when storing ammonia water. Such safety requirements include, for instance, ex-proof equipment in the tank, ammonia sensors, illuminated wind direction indicators, over pressure/vacuum relief valves with flame arrestors, gas exchange pipes, emergency showers, eye showers, etc.

There are basically two typical design concepts of coal fired boilers. The main boiler design has two flue gas passes and a contraction nose at the end of the furnace. The other design is the tower boiler. The significant differences which have an impact on the SNCR technology are as follows:

In the two pass boiler, the vertical flue gas flow is directed towards the front wall of the boiler by the contraction nose (**Figure 23**). At the front wall it is turned horizontally and directed to the platen super heaters. At full load the optimum temperature is mostly in the level of or even within the super heaters. The use of ammonia water as a reagent is often limited by the temperatures which are mostly too high, so that a lot of the ammonia will burn already to NO_x before it can reach the area with lower temperatures within the heat exchangers. Therefore, the overall NO_x-reduction will not be satisfying.

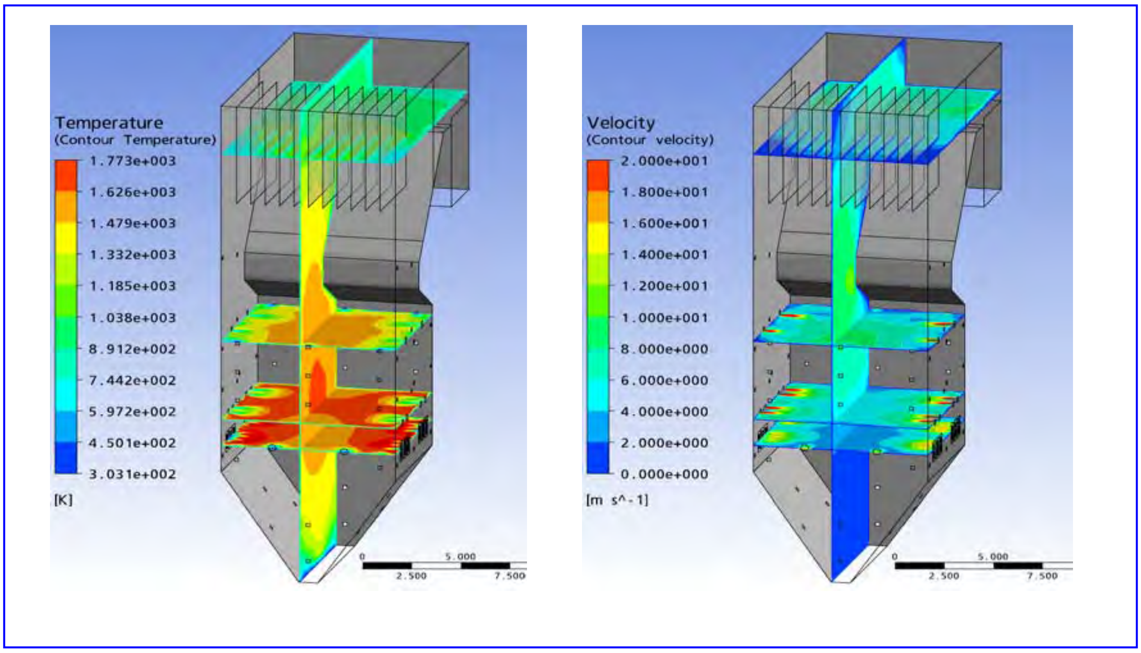

Fig. 23: Temperature and Flue Gas Velocities in a Coal-Fired Boiler

With urea solution this problem is easier to handle since by the time the water droplet surrounding the urea particle has evaporated, the NH_2 of the decomposed urea will have reached the cooler area. However, there is serious concern that droplets containing urea would impinge on the boiler tubes causing corrosion and damage of the tubes. Therefore, special attention has to be paid to the positioning, maintenance and operation of the injectors.

In tower boilers the situation is different, but not easier than in two path boilers, although the reagent can be injected in most applications from all four sides of the boiler. The hot flue gases are streaming upwards through the heat exchangers and the temperatures are decreasing 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 has to be covered with reagent at the different injection levels. Close to the boiler walls is the coldest temperature which can produce high ammonia slip. In the center the temperature is too hot over the whole load range so that the ammonia will burn to NO_x.

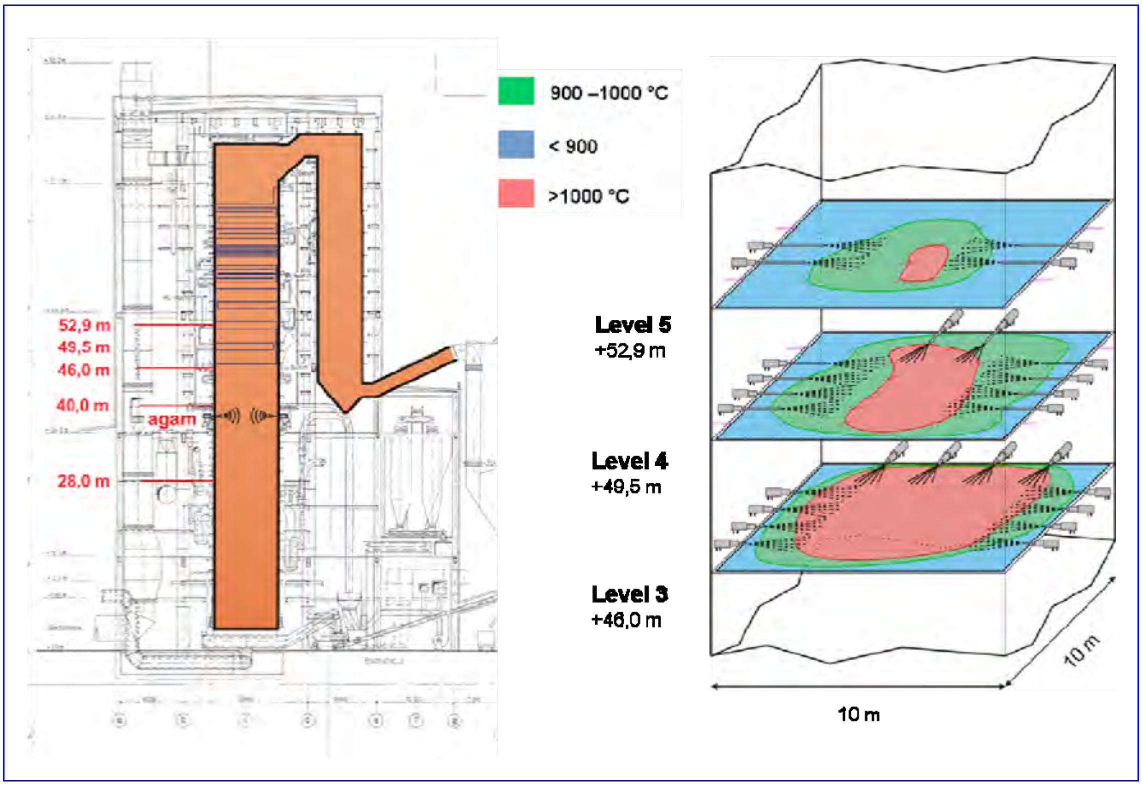

Fig. 24: SNCR Process for a Coal-Fired Boiler in Germany

Only the area marked in green color between those two areas will have an optimum temperature range for the reactions (**Figure 24**). Therefore, special measures have to be taken in order to achieve sufficient distribution of the reagent in the flue gas. One alternative is to inject the reagent in several levels simultaneously with different penetration depths and/or lances with different lengths. However, an optimum distribution of the reagent is still difficult to realize. The temperature changes downstream the level where the temperatures measured are affected by the deposits of fly ash and the operating cycle of the soot blowers. If more than three injection levels are installed a second level with acoustic temperature measurement system will be helpful to improve the performance of the SNCR considerably.

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

It was disappointing to see that the automatic control did not provide better results than achieved with the manual 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 reagents.

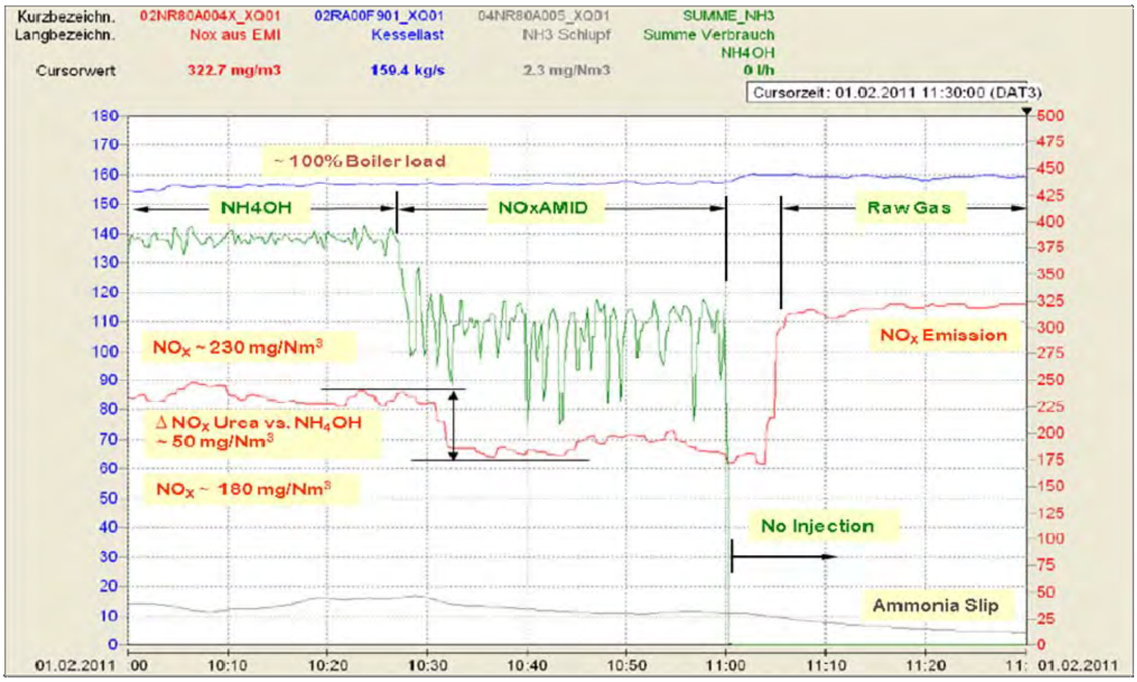

Fig. 25: Operating Results – Injection with NO_xAMID

The results showed that immediately after injection of urea the NO_x-reduction increased and the consumption of the reagent decreased (**Figure 25**). 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.

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 as discussed above.

The tests proved 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.

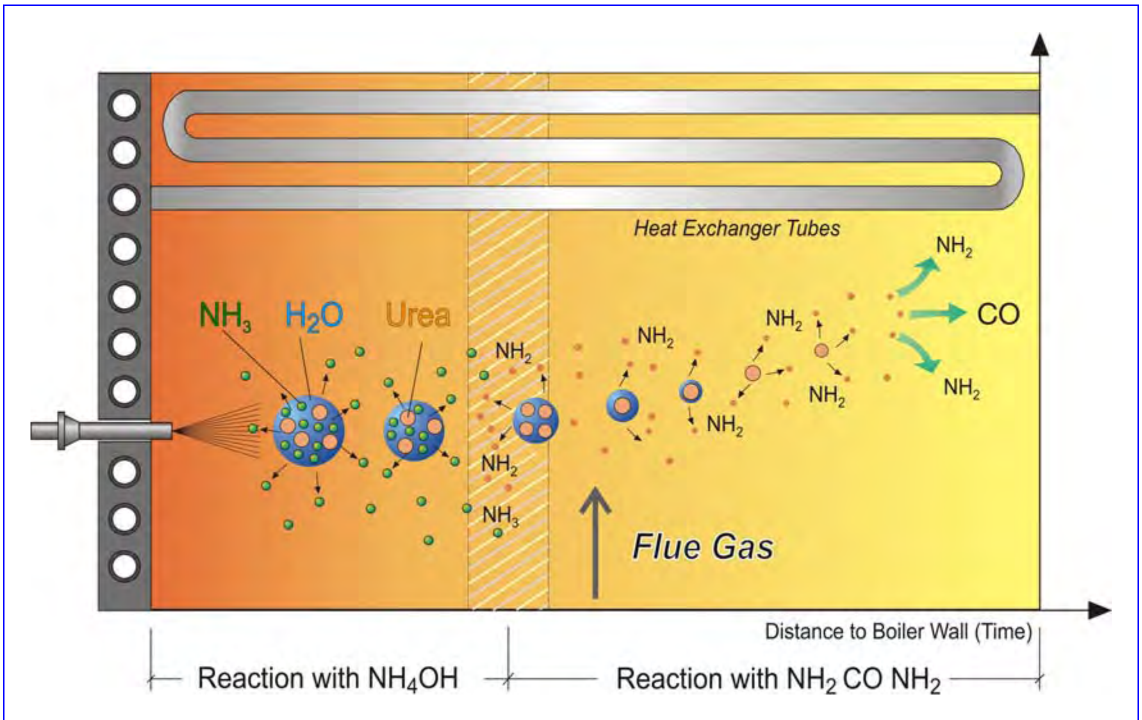

Fig. 26: NO_x Reduction - Mixing of Ammonia Water (NH_4OH) and Urea (NH_2 CO NH_2)

Thereafter, it was only a small step to mix both reagents together and inject various mixtures into the furnace, in order to combine the respective features (**Figure 26**).

Now a commercial plant has been built 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 named TWIN-NO_x process now (**Figure 27**).

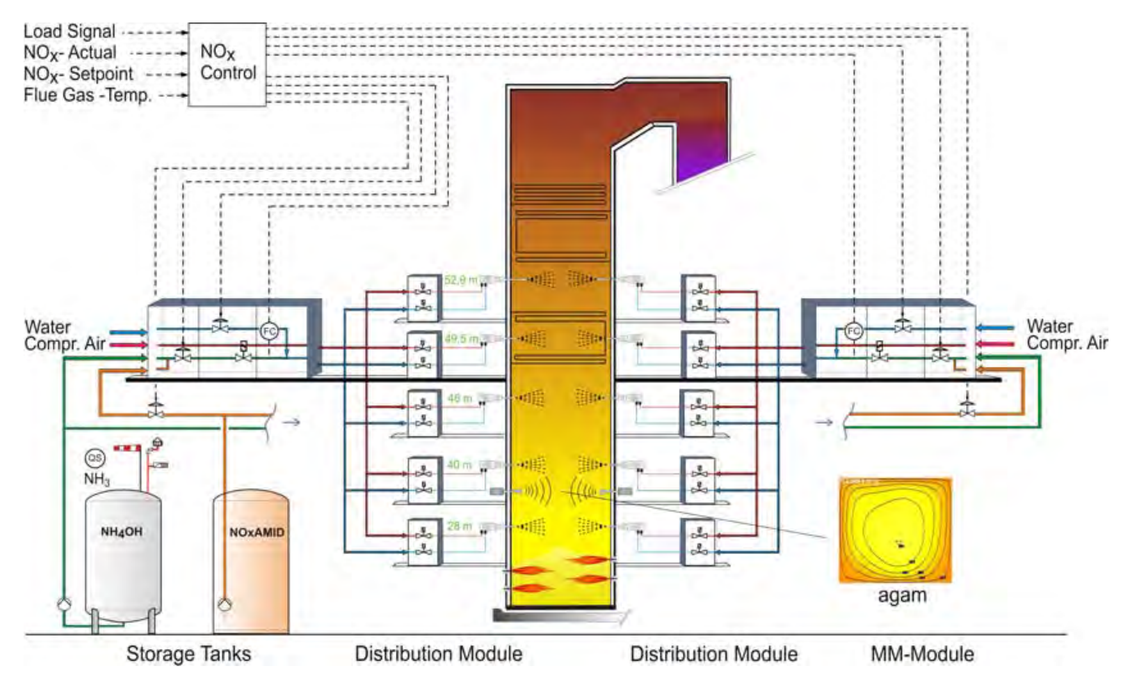

Fig. 27: TWIN-NO_x SNCR-Process with Five Injection Levels for Mixing Ammonia Water (NH_4OH) and Urea Solution (NO_xAMID)

10. Potential for the Future

Nowadays, the results achieved with SNCR-technology alone can definitely be compared to those of catalytic NO_x-reduction, however, at a fraction of the cost. For many years, SNCR-technology has been defining the state-of-the-art for grate-firing-systems, like for example waste incineration plants.

Upon introduction of the temperature controlled changing of individual lances, even in large combustion plants a degree of NO_x-reduction can be achieved, which was not possible only a few years ago. The changing of lances depending on varying temperatures can only be a reaction to variable and sub-optimal operating conditions of the furnace. It would be much better to homogenize the temperature profile and velocity of the flue gas during the combustion process before the reagent is injected.

This would reduce the requirements for the SNCR control-system and, since the changing of lances would have to take place less frequently, oscillation of the control-system would be prevented while at the same time more homogenous NO_x clean gas concentrations would be achieved.

A significant improvement of the temperature profile and the prevention of extreme NO_x peaks could be obtained, if the temperatures measured by the agam-system were used not only for the regulation of the SCNR-plant but also for optimizing the combustion process. Little additional effort would be required as most components which would be needed are already installed in the SNCR-plant.

Furthermore, all technological measures like optimizing the combustion and flue gas recirculation should be taken if they are technically feasible as well as commercially justified. With a small additional slice of catalyst at the tail end of the boiler, the ammonia slip could be minimized. (**Figure 28**)

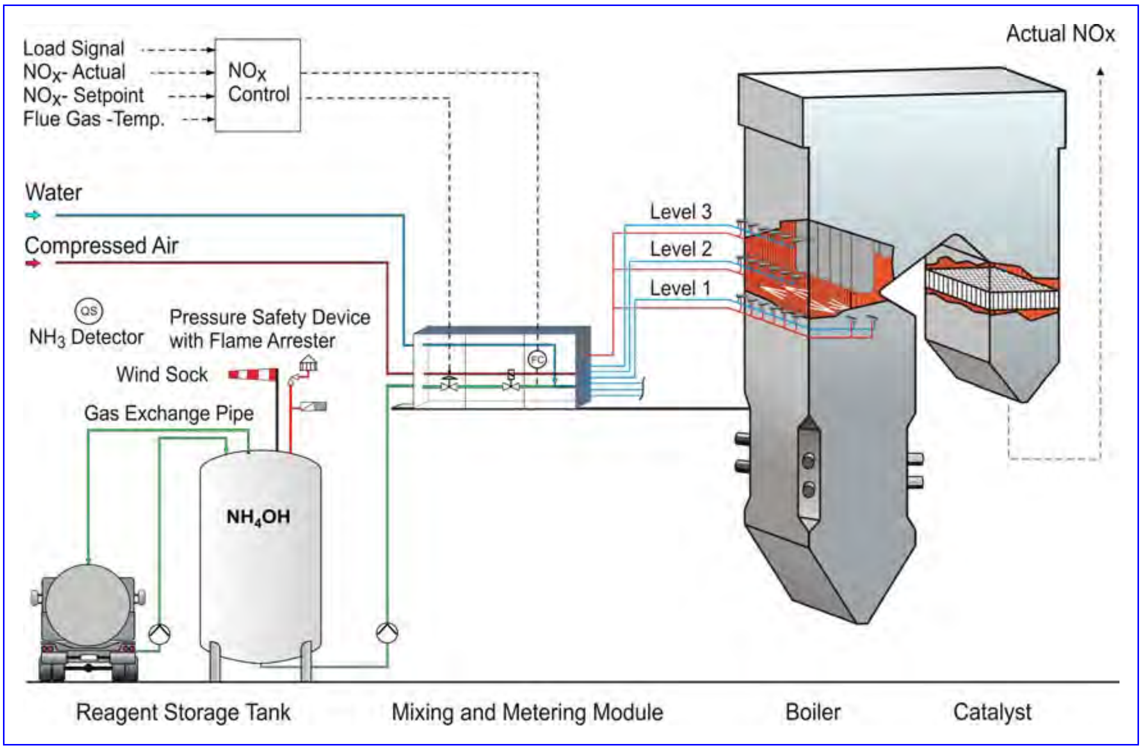

Fig. 28: Process Flow Diagram with Ammonia Water and Catalyst

New boilers could be designed in such a way that they meet the requirements of SNCR which are basically the extension of the space in the area of the injection levels. The cost involved would be negligable in comparison to the cost of the whole project.

With the new TWIN-NO_x process further potentials and improvements are expected.

11. Summary and Outlook

Over many years of experience in continuous operation in various combustion plants, the SNCR-process has proven to be a reliable and economical process for NO_x-reduction to meet the required NO_x limits. In the discussed power plants all expectations were met and mostly exceeded to a considerable extent.

From the process point of view, it is practically of no relevance whether urea solution or ammonia water is used as reagent. If plants are engineered, installed and operated in an appropriate manner, both media are not expected to have an impact on the availability of the overall plant.

In Germany, Sweden and the Netherlands SNCR for MSW plants have been operated for several years, which had been designed for NO_x limits of < 100 mg/Nm³. These plants reliably comply with the guaranteed values in continuous operation. The newer plants, which are equipped with an acoustic temperature measurement (agam) and three injection levels for the changing of individual lances, feature a specifically low NH_3 slip apart from their low NO_x clean gas values and high efficiency.

Although slightly higher NO_x-reduction levels are achievable with the SCR-technology, the cost-benefit ratio is mostly not as good as with the SNCR technology - in particular when taking into account that by now, NO_x values below 300 mg/Nm³ are generally obtained for large coal-fired boilers with combustion modifications alone.

During the decision-taking process for a denox system, some consideration should be given to the fact that the protection level for the environment in the sense of BAT is mostly not achieved with SCR. The investment costs for one SCR plant alone, for instance, are so high that five to ten SNCR plants could be built for that amount. Each of them would be able to comply with the future NO_x regulations and all these plants together would assure multiple reliefs for the environment, at the same time lowering the costs for the owners compared to one SCR plant alone.

Test results from oil and coal-fired combustion plants with a capacity of up to 225 MW_{el} are promising. In the accession countries Poland and the Czech Republic first decisions in favor of the SNCR technology for large power plants are expected to be taken within the coming two years.

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