Next Generation of SNCR Technologies
- Developments and Improvements for Power Boilers -

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1. Introduction

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. These types of boilers like waste-to-energy plants are generally designed in such a way that the first flue gas pass is free of heat exchangers so that the injection and distribution of the reagent into the optimum temperature window can easily be realized. While the demands for low NO_x emissions increased over the years the SNCR process was continuously improved.

For these applications, NO_x limits of 100 mg/Nm³ and lower can be achieved and maintained now at all operating conditions. 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.

With this in mind, an increasing number of utility companies have already installed SNCR plants or are seriously investigating to use this technology for their large boilers as well. Besides the NO_x reduction and overall cost compared to SCR, special attention is also being paid to the formation of ammonia salts caused by the ammonia slip in the flue gas and the effects on fly ash, gypsum and waste water of the FGD downstream the boiler. This requires a comprehensive understanding of the different combustion systems and boiler designs.

This paper describes 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 assessed, applied and consequently developed further to meet the ambitious demands of the regulators.

2. 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 sometimes 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 byproduct of flue gas cleaning

3. Operating Experiences with Various Boilers

3.1. Operating Experiences with a Waste-to-Energy Plant (WtE)

Grate-fired boilers are most suitable for SNCR since the space above the grate in the first flue gas pass provides sufficient room and residence time at the optimum temperature before the flue gas enters the heat exchangers. Therefore, NO_x reductions below 100 mg/Nm³ represent the state of the art for this type of boilers fired with municipal waste, RDF, biomass etc.

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. Apart from the economical advantages, the precondition for this decision was that the NO_x emissions approved by the authorities for the SCR will also be maintained for 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 approx. 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 1).**

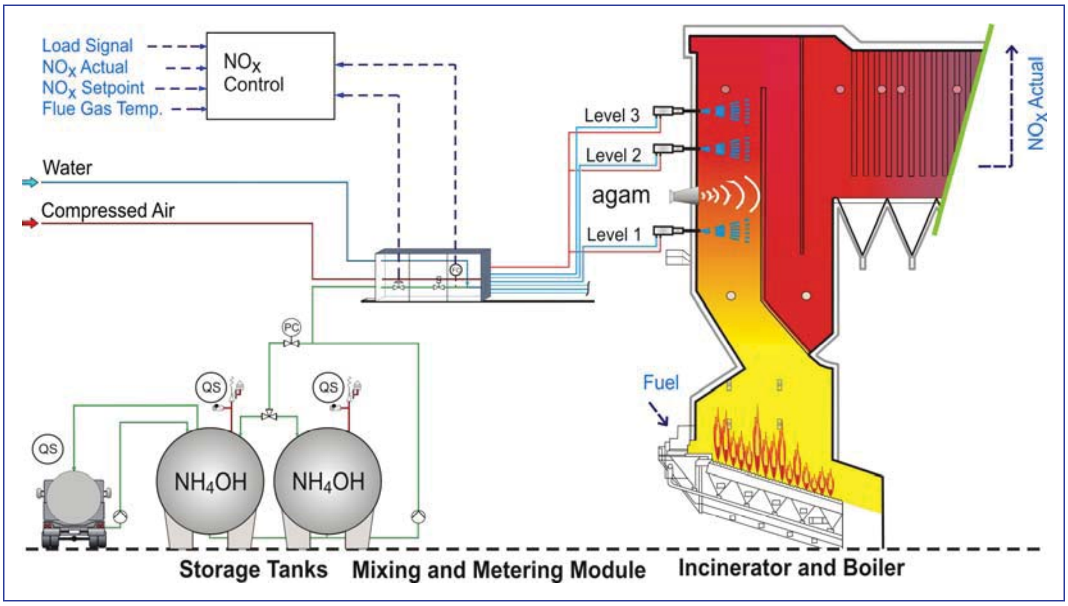


Fig. 1: Flow Chart SNCR Plant with agam and Three Injection Levels

Compared to the SCR, the savings of natural gas for reheating the flue gas upstream the catalyst are 6.6 million Nm³/a and approximately 6,100 MWh/a savings in electricity, since no energy is needed to overcome the pressure drop in the catalyst.

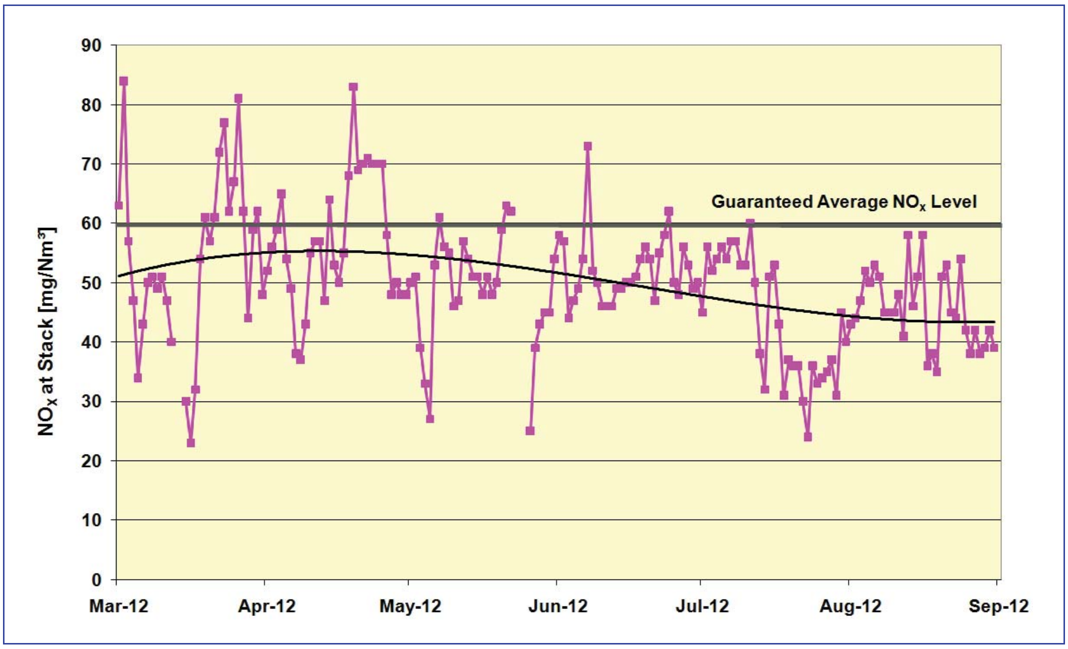


Fig. 2: Daily Averages Line 11 – March to September 2012

The first incineration line was put into operation in March 2012, the second one in September 2012 and the third one in April 2013. The plants are operating to the full satisfaction of the operator at extraordinarily low NO_x emissions of 50 mg/Nm³ (**Figure 2**).

3.2. Liquid Fuel

Boilers fired with liquid fuels usually have smaller combustion chambers as grate-fired boilers. 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. Below solutions for two different applications are described.

3.2.1. Incineration Plant for Liquid Waste

Figure 3 shows two incinerators which are burning liquid waste with a wide range of fuel composition. The first boiler (No. 7) was put into operation 2004, the other one (No. 8) is under construction and will be 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 levels < 60 mg/Nm³under all operating conditions.

In order to avoid the turbulences and back flows of the flue gases, which caused the temperature imbalances in boiler 7, boiler 8 is being built without heat exchangers in the second pass (**Figure 4**). In boiler 7 the injectors were installed close to the boiler wall where the velocity is fastest and the NO_x freight is heaviest.

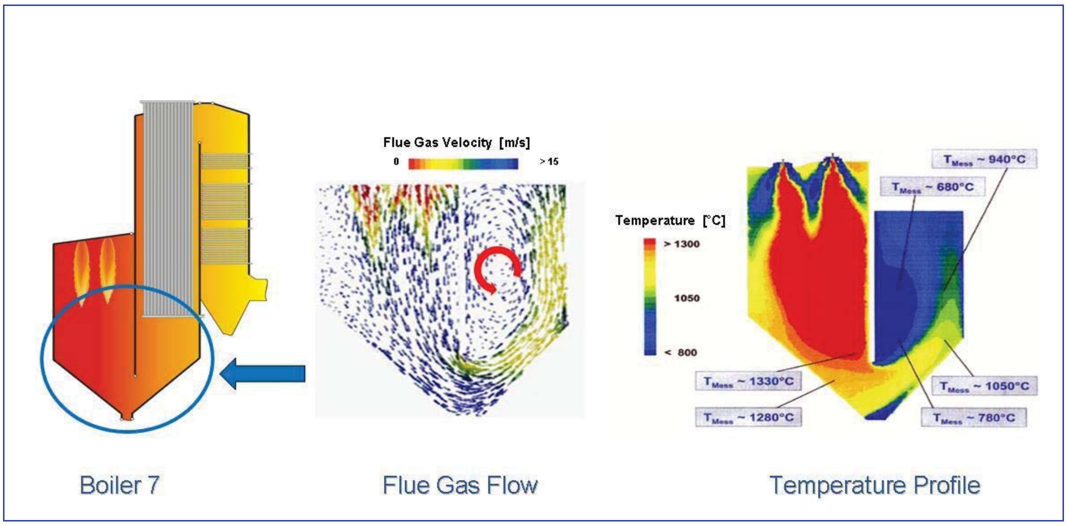


Fig. 3: **Flue Gas Flow and Temperature Profile in a Boiler for Liquid Waste**

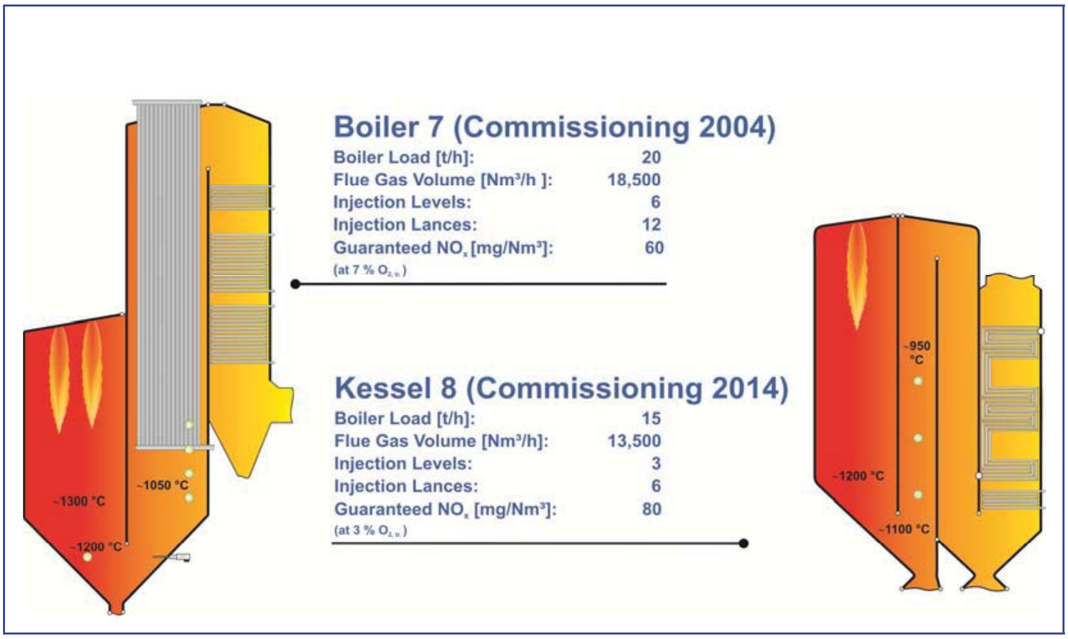


Fig. 4: **Operating Data and Boiler Design for Liquid Waste**

3.2.2. Oil-Fired Boilers

Following extensive feasibility tests with urea solution two oil fired boilers in Germany with a steam capacity of 154 t/h each were equipped with SNCR using ammonia water as reagent. During the commissioning of the commercial plant it turned out that in the upper load range the required NO_x reduction could not be achieved due to the prevailing high flue gas temperatures and velocities before entering the heat exchangers (**Figure 5**). Additional trials confirmed the assumption that the results with urea solution are better, because the high volatile ammonia obviously reacts too early in locations where the flue gas is too hot, while the reaction with urea would take place in the cooler area within the heat exchangers.

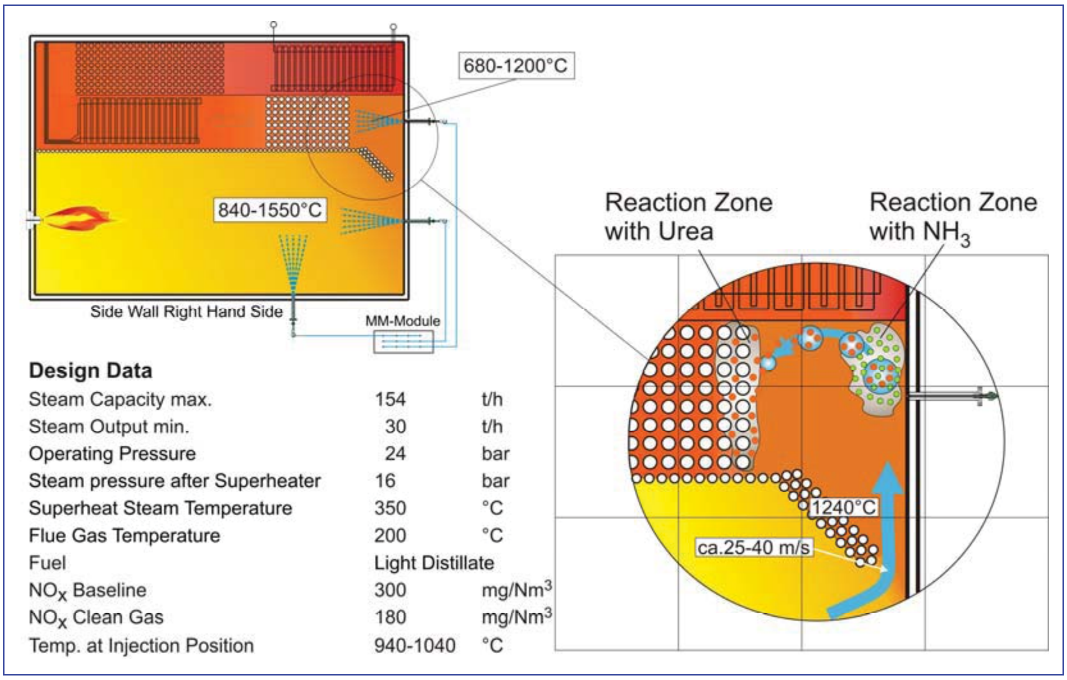


Fig. 5: Reaction Zones of Urea and Ammonia Water in a Fire Tube Boiler

The plant was modified thereafter with the TWIN-NO_x process i. e. at boiler loads up to 80 % only ammonia water is injected as reagent. Above this load urea is increasingly blended into the reagent while the ammonia content is decreased. At 100 % boiler load only urea is injected (**Figure 6**) After this modification (**Figure 7**) the guaranteed NO_x emissions < 180 mg/Nm³ can be maintained at all boiler loads.

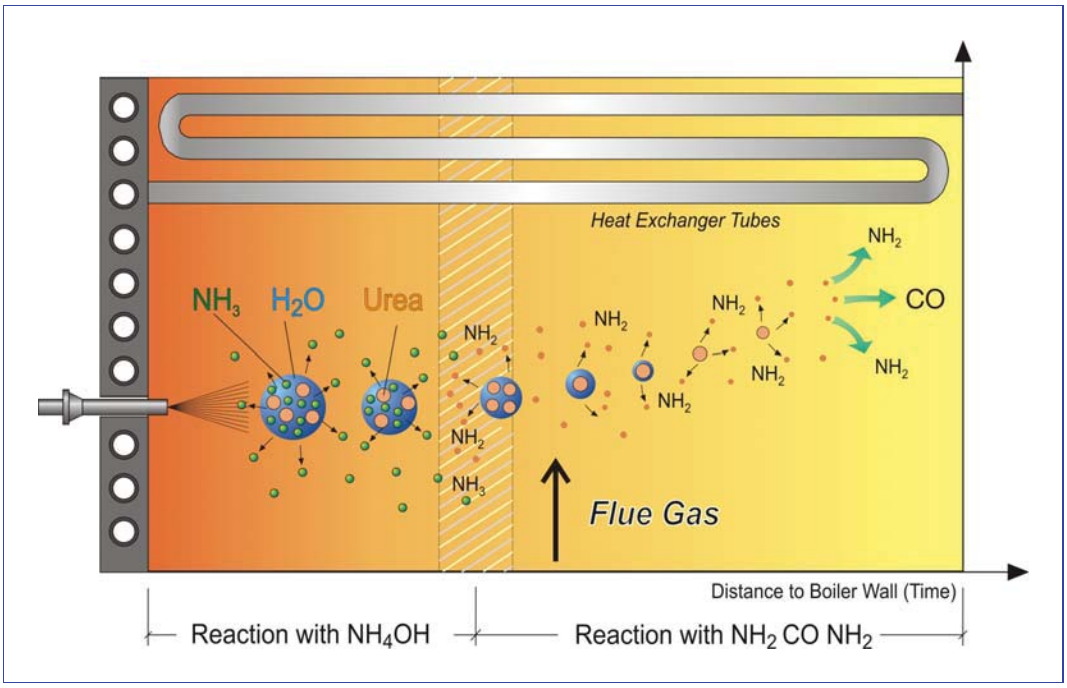


Fig. 6: TWIN-NO_x – Mixing of Ammonia Water and Urea Extends the Temperature Window

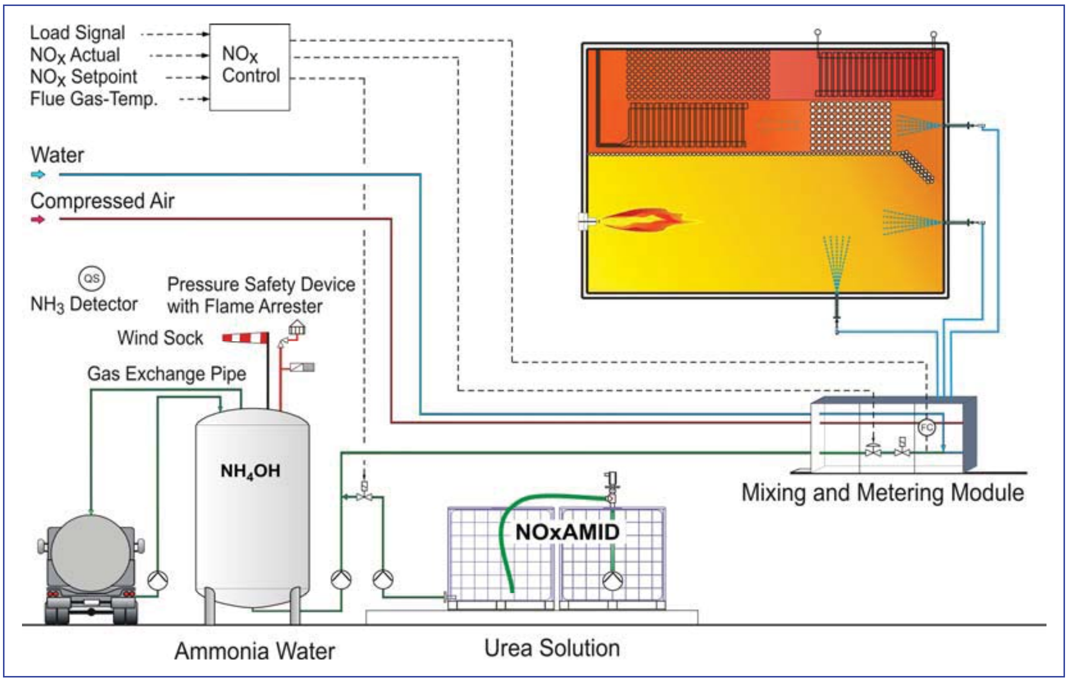


Fig. 7: **Fire Tube Boiler with TWIN-NO$_x$ Process**

3.3. Coal-Fired Boilers

Common designs of coal-fired utility boilers are boilers with two flue gas passes, a nose and platen heat exchangers at the end of the furnace and further heat exchangers in the second pass. In the tower boilers the heat exchangers are installed horizontally above the furnace. The significant differences in the designs which have an impact on the SNCR technology are as follows:

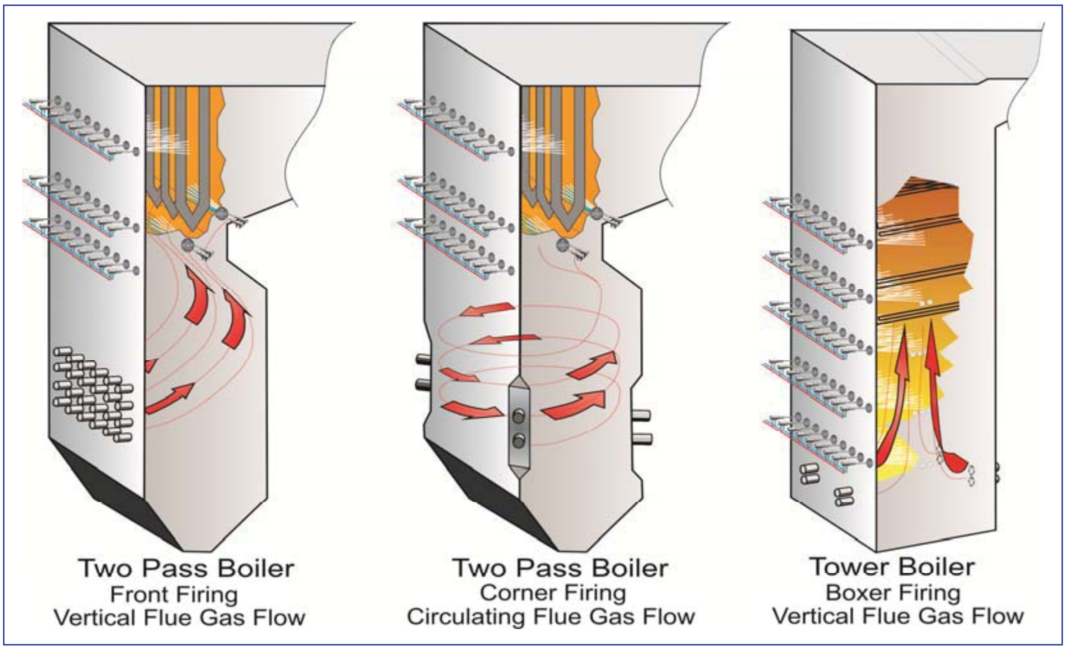


Fig. 8: **Effects of Different Burner Configurations on Flue Gas Flow**

In two pass boilers, the nose at the end of the furnace directs the vertical flue gas flow towards the front wall of the boiler and the heat exchangers depending on the burner configuration (**Figure 8**). At full load, the optimum temperature is generally in the level of or even within the super heaters. Therefore, a homogeneous distribution within the flue gas at the optimum temperature is not possible, and compromises in the performance of the SNCR have to be accepted, especially when the injection between the heat exchangers is not feasible at reasonable technical efforts and costs (**Figure 9**).

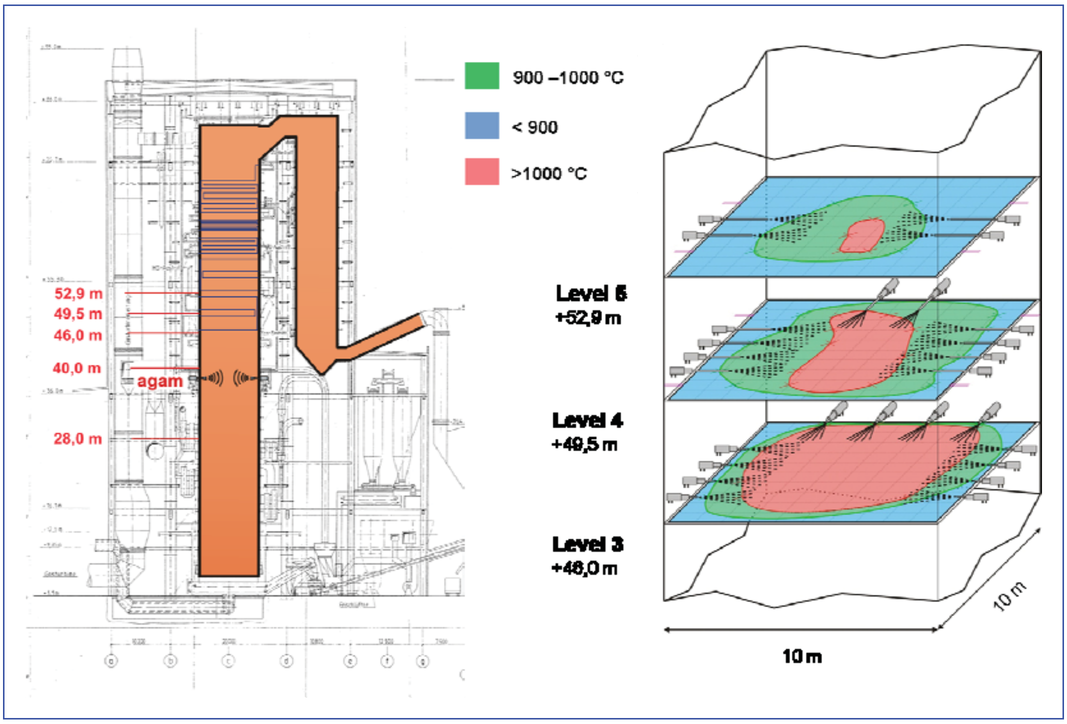


Fig. 9: **Typical Temperature Distribution in Coal-Fired Tower Boilers**

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

Only the area marked in green color between those two areas has an optimum temperature range for the reactions (**Figure 10**). 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 into several levels simultaneously with different penetration depths and / or lances with different lengths. An optimum distribution of the reagent is still difficult to realize. The temperatures change considerably downstream the agam measuring level, because they are affected by the deposits of fly ash and the operating cycle of the soot blowers.

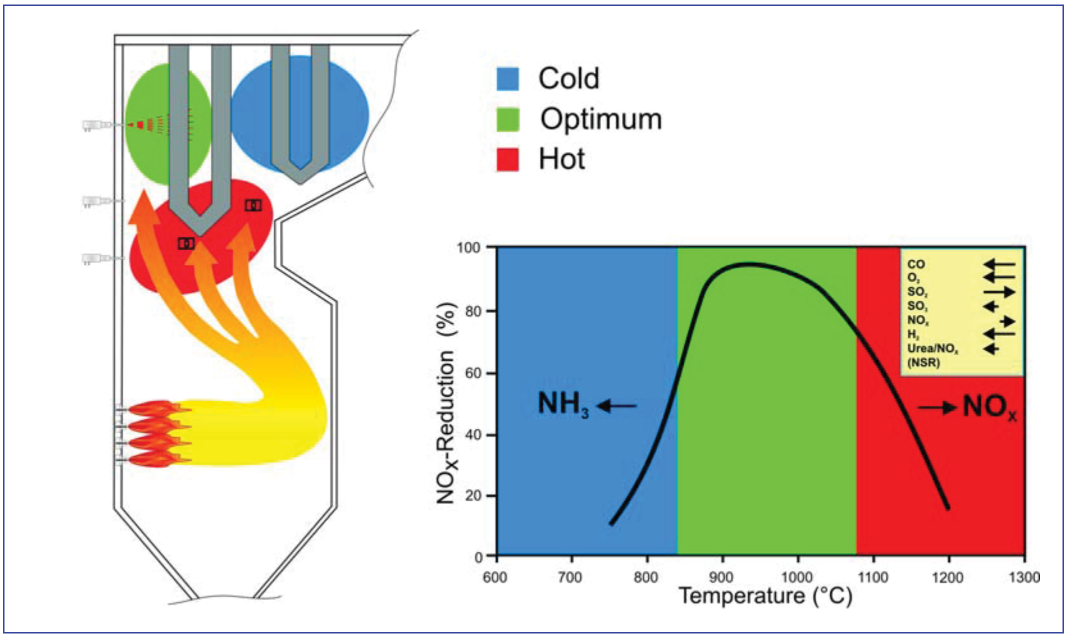


Fig. 10: Typical Temperature Distribution in Coal-Fired Tower Boilers

3.3.1. Pulverized Coal-Fired Boiler (ca. 200 MW_{el}) in Völklingen, Germany

The simplified process diagram **(Figure 11)** shows the function and the scope of supply of the commercial SNCR plant as designed, installed and commissioned in a power plant in Völklingen, Germany. Due to the significant variations in flue gas velocity and flue gas temperatures between low load and full load as well as the extreme temperature imbalances, five levels with 12 injectors per level 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 of the 60 injection lances can be individually activated or deactivated in order to assure that the reagent always reaches the flue gas at the optimum temperature.

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 reagents, compressed air and process water.

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 %.

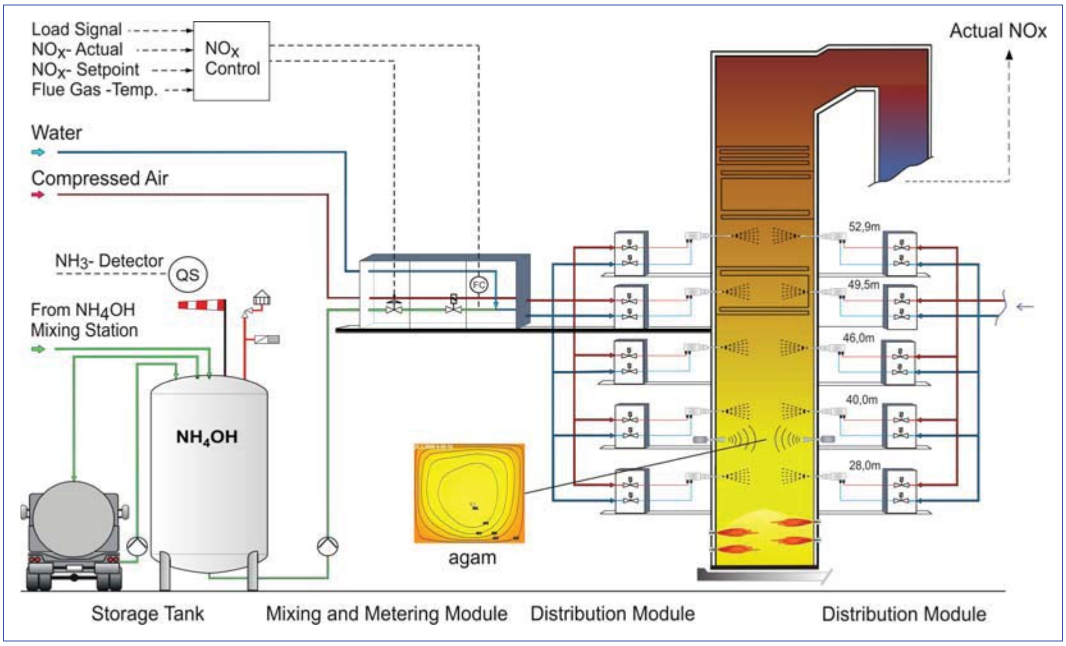


Fig. 11: Process Diagram - SNCR with Five Injection Levels and agam

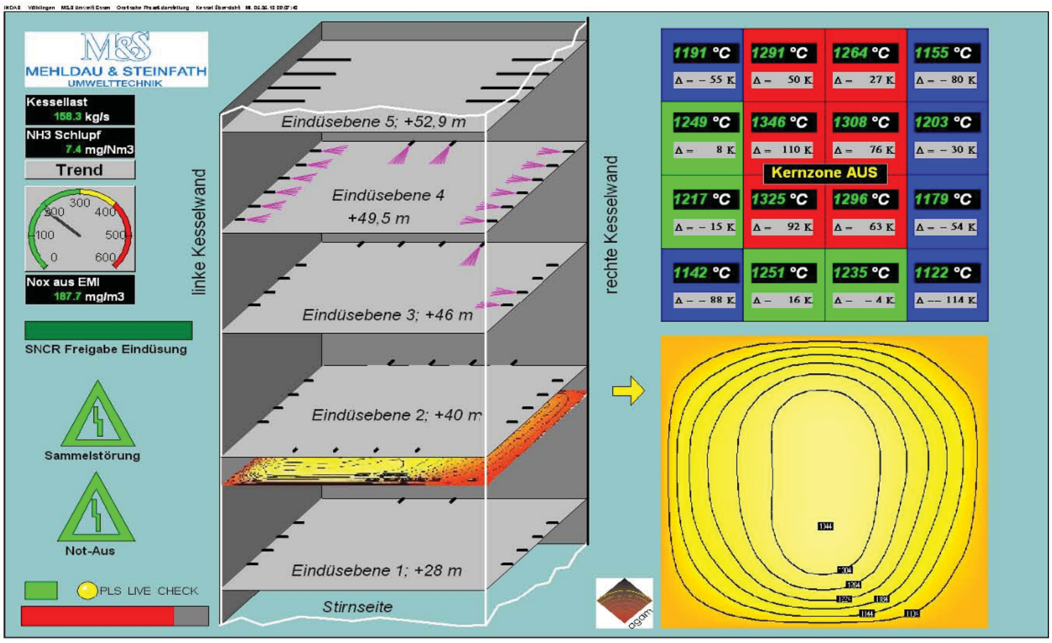


Fig. 12: Display of Temperature Profile, Average Temperature in Zones, Injectors in Operation

The operating principle of an SNCR following the temperature profiles and average temperature in the zones established with the acoustic temperature measuring system (agam) is illustrated on the display of the control system (**Figure 12**).

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

At the location Jaworzno, Poland, six coal fired boilers of the same type (OP 650) are operating (**Figure 13**). The major difference to similar boilers where trials had been executed is that these boilers are equipped with front firing instead of corner firing. In addition, the distance between the front wall and the platen heat exchangers is only 1.8 m compared to 6.0 m.

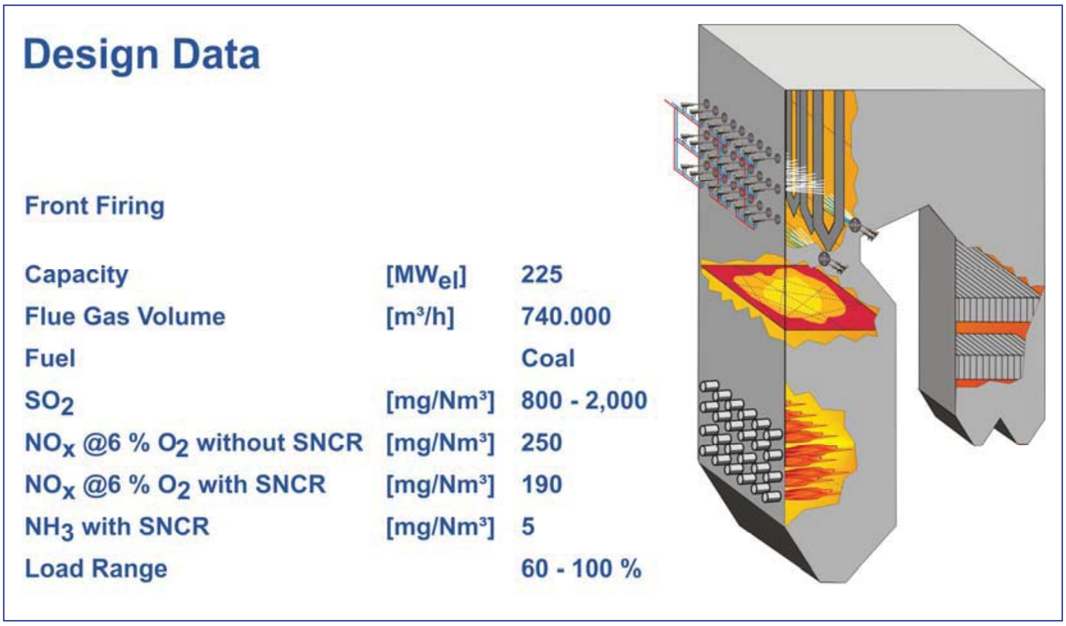


Fig. 13: Design Data of a Coal-Fired Boiler with Front Firing in Jaworzno, Poland,

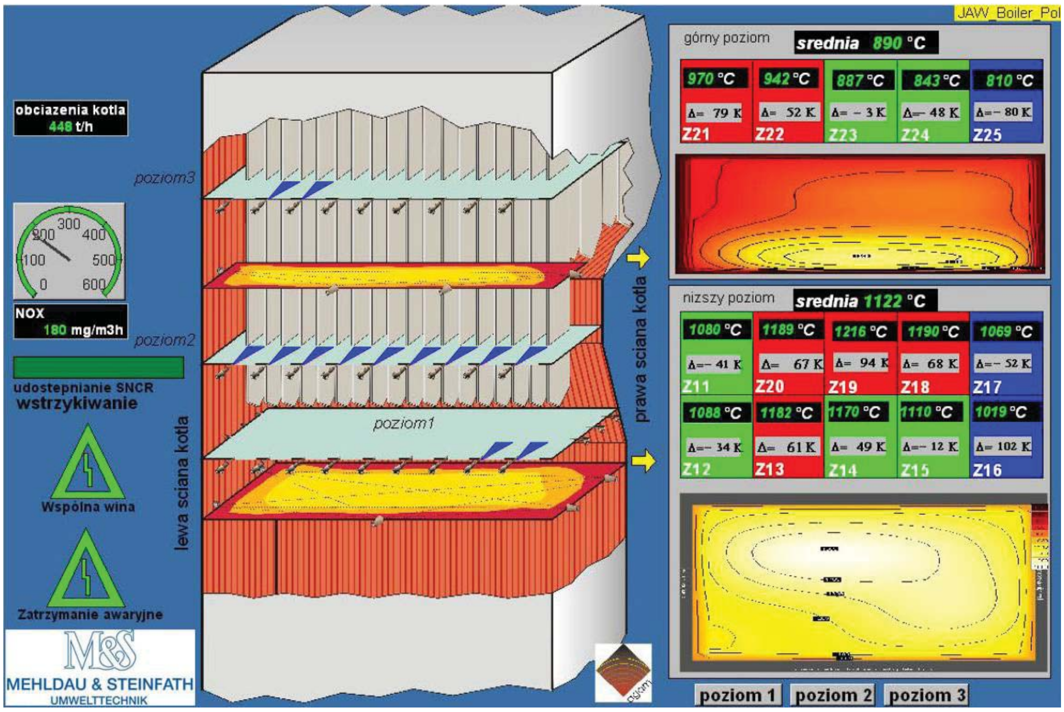


Fig. 14: Display with Temperature Profiles in 2 Levels, Injectors in Operation, Perfomance Data

After retrofitting of the combustion had been completed a commercial SNCR was installed for one of these boilers. For the optimum arrangement of the injectors the experiences gathered during the trials were applied as much as possible.

The major improvements compared to the trial plant are that three injection levels have been installed in order to follow more closely the load changes of the boiler. 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. The second level is used to obtain more precise information on the flue gas temperatures near the injector positions and the temperature gradient between the two agam levels (**Figure 14**).

Temperature imbalances of up to 200 K were measured from the right to the left side of the combustion chamber. The following reasons were identified:

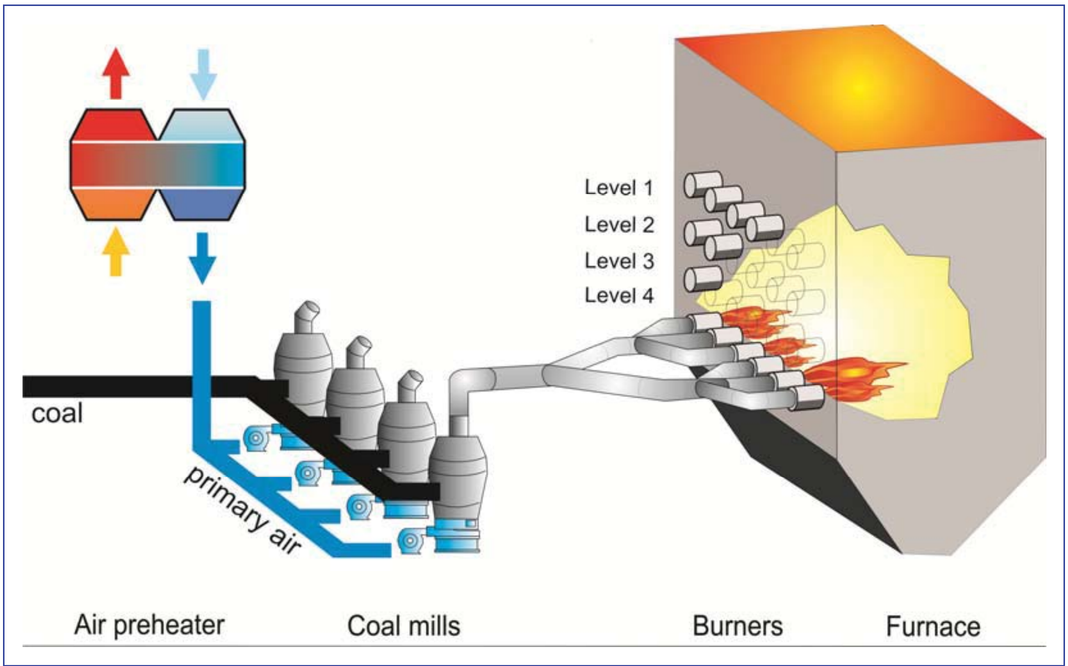


Fig. 15: Irregular Combustion Caused by Uneven Coal Distribution

- Each coal mill supplies six burners with coal and primary combustion air. Due to various coal deposits in the coal and air ducts, it is practically not possible to evenly distribute the coal and air to the burners and assure a balanced combustion of all burners simultaneously (**Figure 15**). As a result of this, the temperature distribution in the furnace varies considerably.
- The burners are installed at the front wall of the boiler so that the flue gas flow is directed straight to the entrance of the heat exchangers. Due to the relatively short residence time, temperature imbalances cannot be equalized and temperatures at full load are too hot at the entrance into the heat exchangers close to the nose.

- In tangentially fired boilers the flue gas flow is forced into a rotary motion. Because of the longer distance to the exit of the furnace, the flue gas cools down more than in front fired boilers. Furthermore, the flue gas is better mixed so that temperature imbalances do not cause major problems.

The 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.

A second boiler was completed in September 2012 and a third one in September 2013. A fourth one is under construction and expected to start operation end of 2014. 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 second boiler was 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 (**Figure 16**). This results in lower ammonia slip, both in the flue gas and the ash and decreases the consumption of ammonia water.

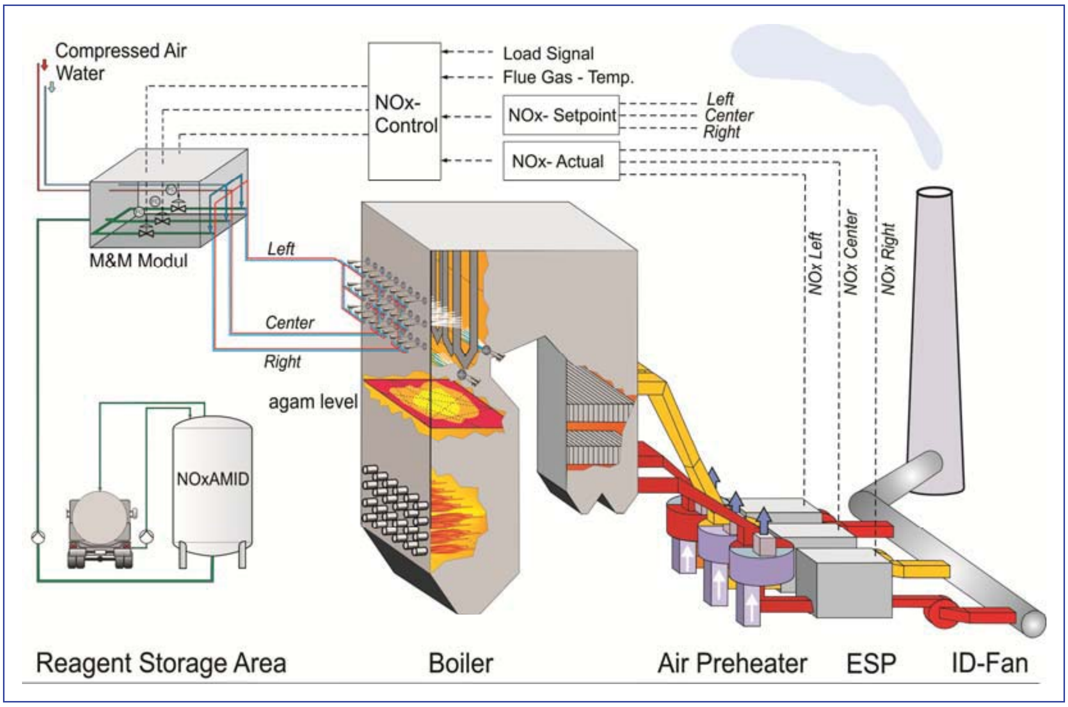


Fig. 16: Flow Chart with 3 x NO_x Control Valves to Limit Slip

In combination with the primary measures the required NO_x level < 200 mg/Nm³ is maintained at all operating conditions. The ammonia content in the ash is below 50 mg/kg (**Figure 17**). The injection lances and the mixing and metering module installed in Jaworzno are shown on **Figures 18 and 19.**

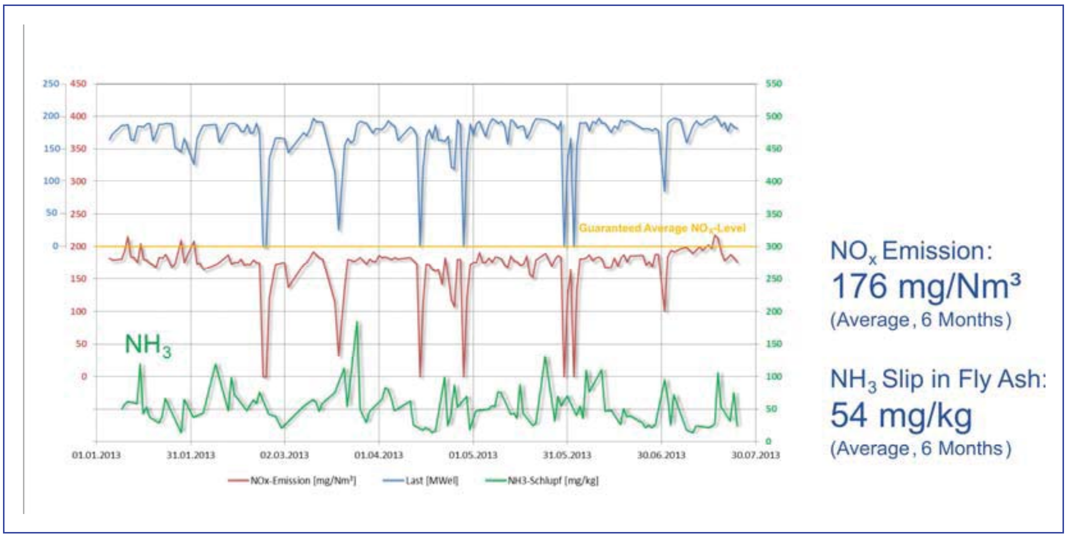


Fig. 17: NO_x Emission and Ammonia Slip in Fly Ash

Fig. 18: Lances

Fig. 19: Mixing and Metering Modules

The flue gas temperatures at the exit of the furnace are often too hot for the SNCR process, especially at full load. The injection of the reagent into a location between the heat exchangers where the temperatures are more suitable is sometimes possible, but can only be realized with a lot of technical effort and at high costs in existing boilers. In new boilers, sufficient space could be provided with reasonable effort, if it were already considered during the planning stage of a project.

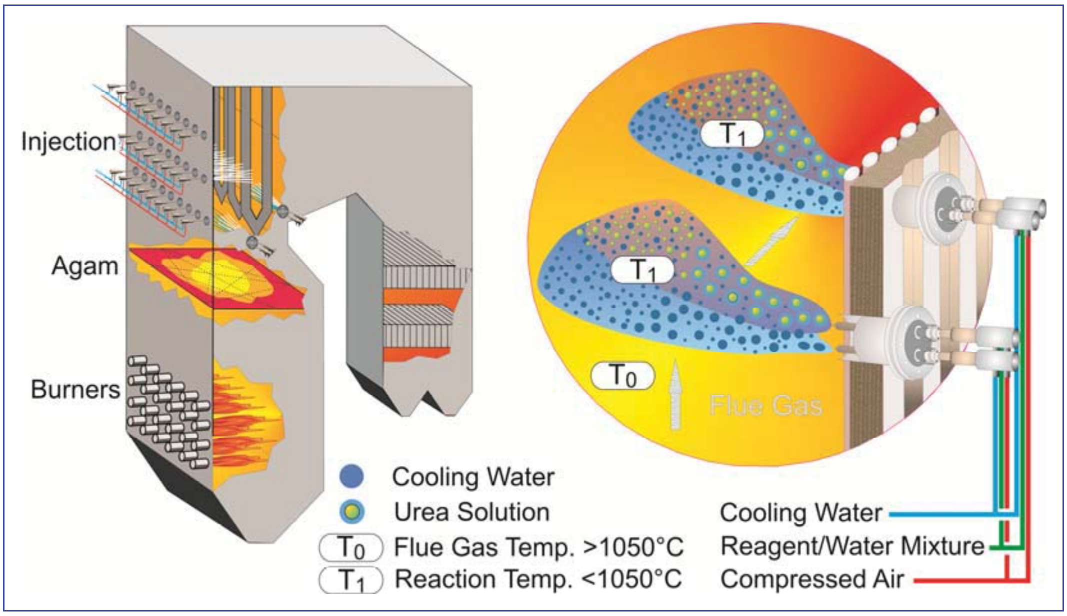


Fig. 20: **Selective Cooling of Flue Gases for Coal-Fired Boiler**

In cases when the flue gas temperatures are too hot, as is mostly the case at peak loads and/or in limited areas, cooling of the flue gas might be a viable alternative. This could be simply accomplished by increasing the quantity of process water. Since the changing of the fluid flow in the injectors would change the spraying pattern as well, a better solution is to install additional injectors for cooling water close to the respective injectors (**Figure 20**). With this concept, cooling water can be switched on or off when the boiler load respectively the flue gas temperature reaches a preselected level (**Figure 21**). With an acoustic temperature measurement system each injector can be activated independently when needed, depending on the flue gas temperature in this location, while the distribution of the reagent would not be affected.

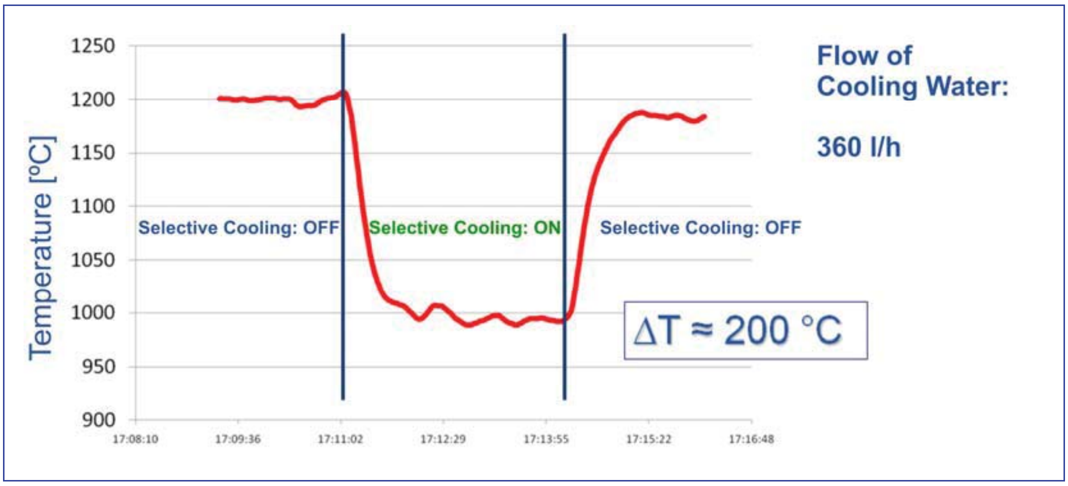


Fig. 21: **Results of Selective Cooling**

3.4. Boiler for Oil Shale

Estonia has significant oil shale resources it is the only country in the world which operates oil shale fired power plants. Approximately 95 % of the electricity in Estonia is generated by burning shale oil. Most of it is supplied to domestic customers but it also can be exported to neighboring countries (**Figure 22**).

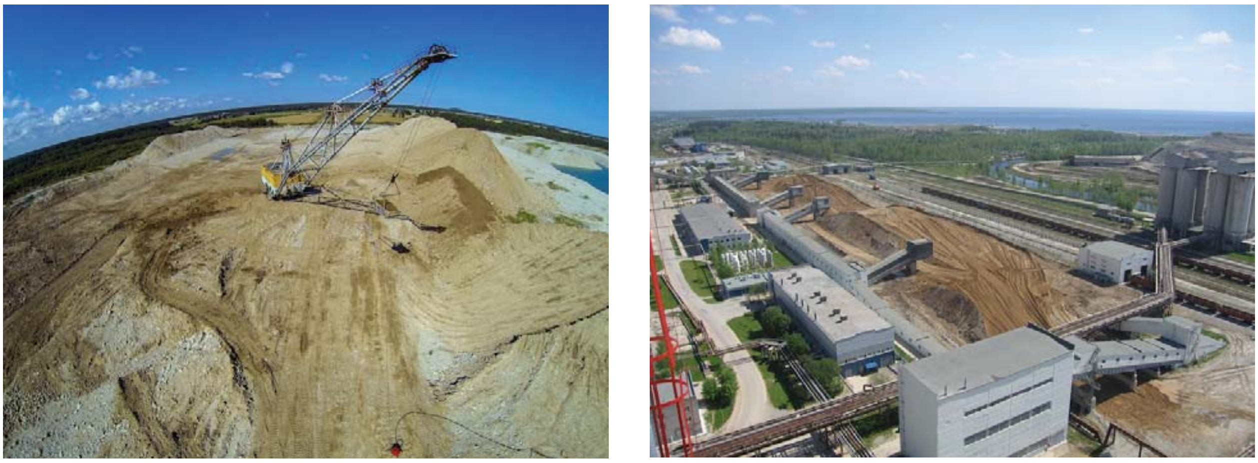
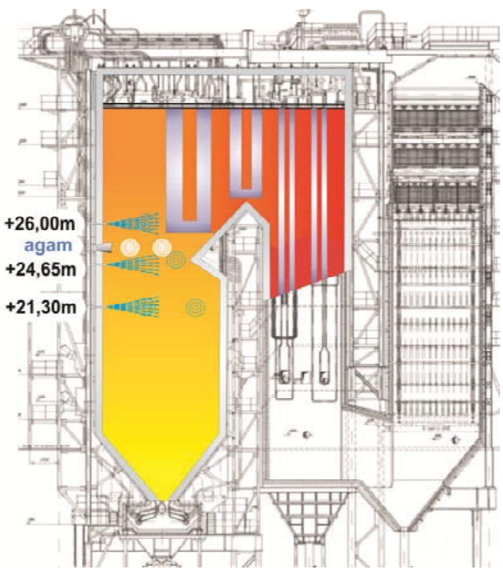


Fig. 22: Narva – Oil Shale

Oil shale as a power fuel belongs to a class with a most complicated organic and mineral composition with a low heating value and high ash content. When designing oil shale fired boilers special attention has to be paid to the ash fouling, the growth of ash deposits on heat exchanger surfaces and the cleaning technology (**Figure 23**).



Boiler Data

Commissioning	1973
Capacity	100MW$_{el}$
Flue Gas	550.000 Nm^3/h
Main Steam Flow	310 t/h
Fuel	Oil Shale
NO_x – Baseline	~ 300 mg/Nm^3
NO_x - with SNCR	< 200 mg/Nm^3

Fig. 23: Design Data of a Boiler Fired with Oil Shale

In Narva, Estonia, an SNCR system has been installed for the first of eight boilers as a commercially operated pilot plant. The objective of this plant is to gather reliable information whether the NO_x reduction in boilers fired with oil shale is feasible or if unknown problems have to be taken into account. Operating results can be taken from **Figure 24**.

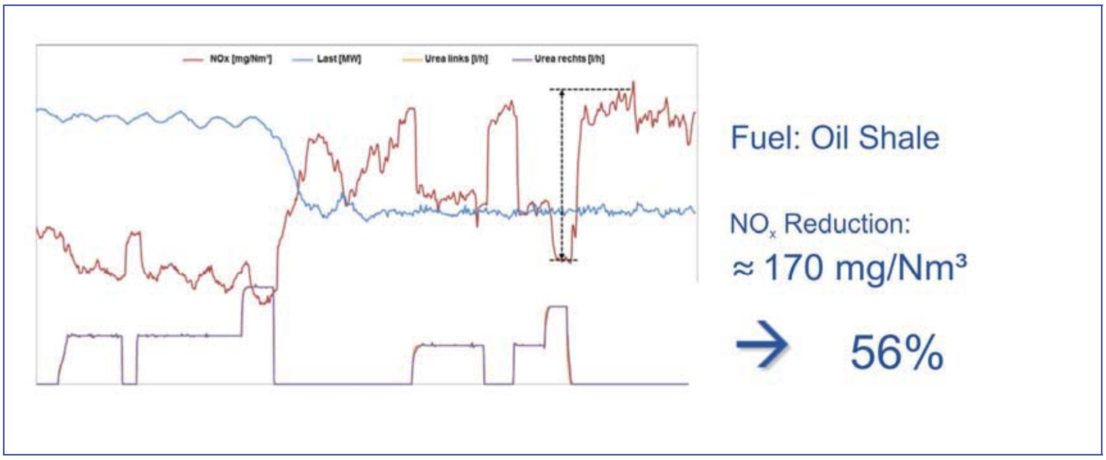
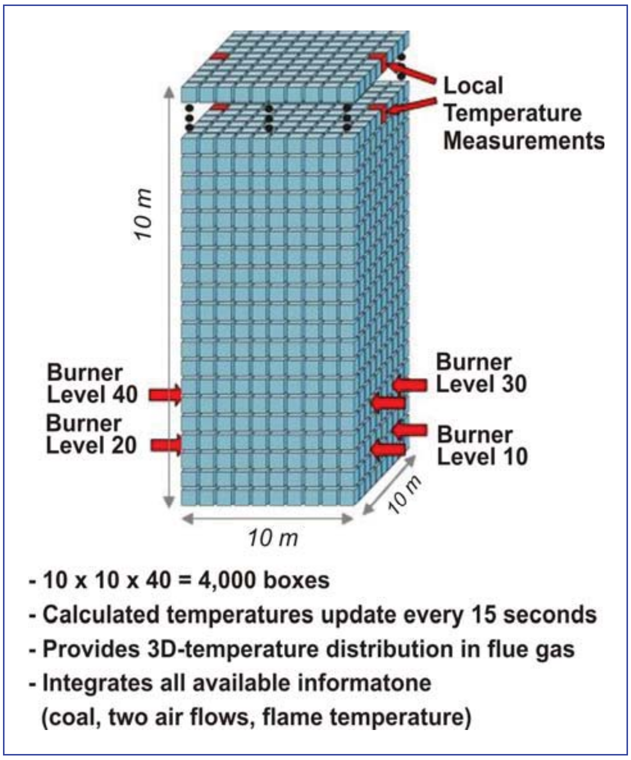


Fig. 24: Narva – Results after Commissioning

4. Process Control

It is not possible to measure the raw and clean gas NO_x concentrations simultaneously in the flue gas with an SNCR plant. Since measurements are performed in the colder flue gas downstream of the boiler, the NO_x content can only be measured alternatingly 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 achieved by means of a load signal, the setpoint 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.



Source: Powitec; VGB Workshop "Flue Gas Cleaning Helsinki", 2011

Fig. 25: Online-CFD

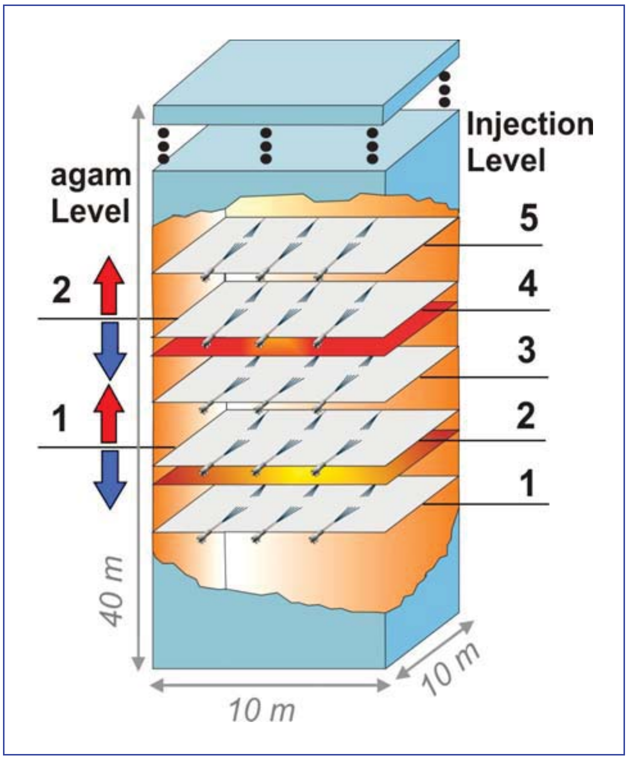
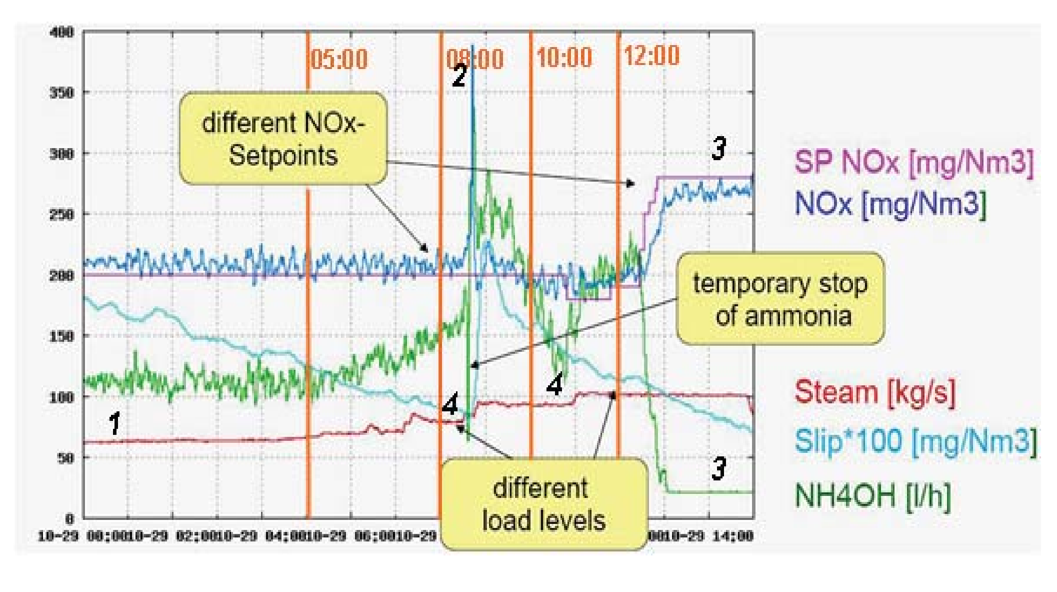


Fig. 26: Acoustic Temperature Measurement (agam)

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 done by a bus connection to the control room. This is common practice, in particular, for larger combustion plants.

After successful performance tests the SNCR plant for MKV Völklingen was handed over to the owner of the power plant. They decided to change the control of the SNCR plant to a new system based on an Online-CFD model. The original control based on the acoustic temperature measurement (agam) was kept on standby for more than a year and could be operated any time after the new control was put into operation. This provided an excellent opportunity to compare both control systems on the identical SNCR hardware.

The supplier of online-CFD (**Figure 25)** claims that more precise information of 3D-temperature distribution in the furnace would lead to a significant improvement of the SNCR performance compared to the standard control system based on the 2D temperature profile provided by agam. However, results show that over the whole load range from 20 to 100 % the online-CFD could not provide any benefits. (**Figure 26)**. The recorded performance data do not even come close to the ones proofed during the acceptance test with the original control system.



Source: Powitec; "VGB Workshop Flue Gas Cleaning", Helsinki, 2011

Fig. 27: SNCR Results: Exemplary Time Plot

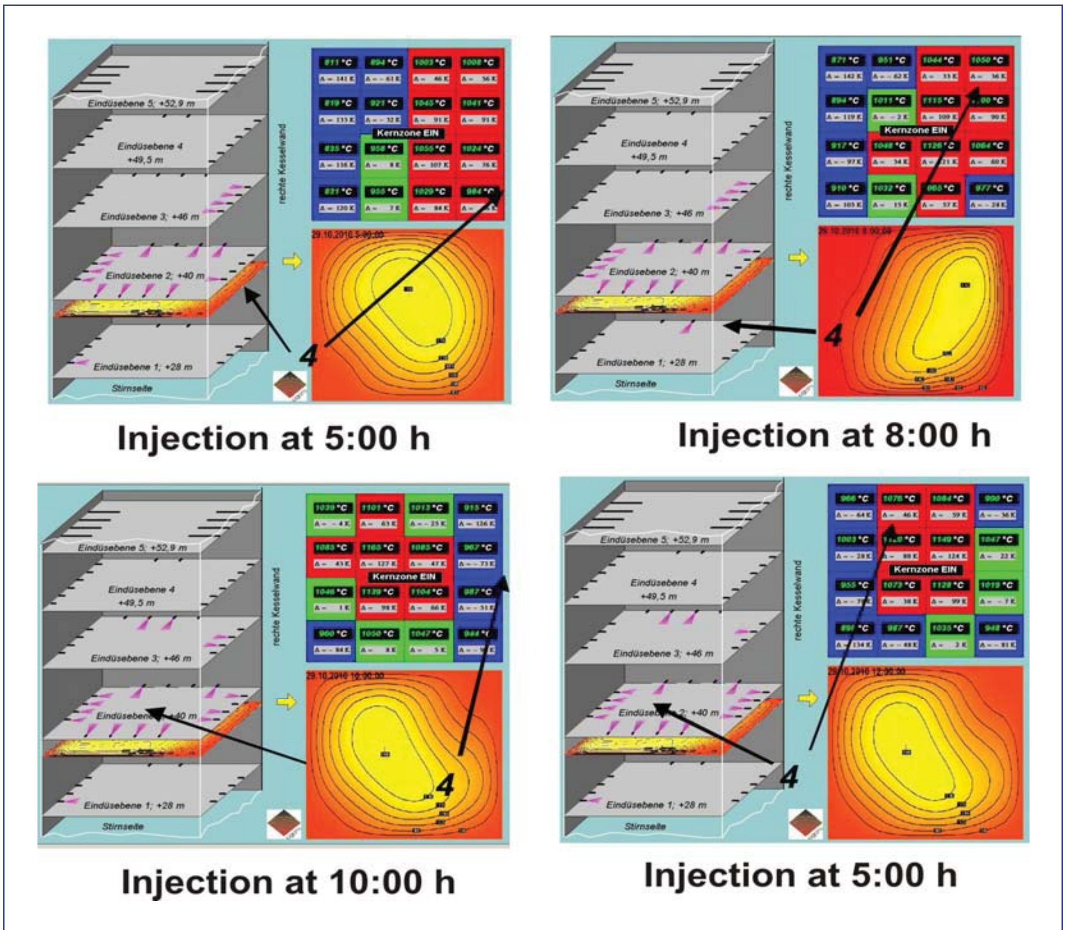


Fig. 28 : Injection Lances in Operation and Temperature Profiles

One reason of the low performance could be that the temperature information of the online-CFD is not sufficient for such a complex system. Another reason probably is that the impact of the flue gas temperatures was overestimated while other parameters of the process, for instance, flue gas velocities and directions, were ignored.

The positions of the injectors in the boiler walls are fixed and cannot be variated to follow the temperatures. Therefore, one level for measuring provides sufficient information for controlling and activating the injection lances in three levels. Since in the Power Plant in Völklingen five levels are installed a second level for measuring the temperatures with agam would be beneficial. The principle for changing the active injectors is as follows:

> If the temperature is ok, the injector stays in level.
> If the temperature is too cold, the injector closer to the burners is activated.
> If the temperature is too hot, the injector downstream the flue gas flow is activated.

A temperature update every 15 seconds, as the supplier of the online-CFD claims important, is counterproductive. Because of the time delay of 3 to 5 minutes between injection of reagent and NO_x measurement in the stack, the control valve needs to be damped.

The graph “SNCR-Results: Exemplary Time Plot” (**Figure 27**) has been published on several conferences. It suggests that the performance of online cfd is superior to other control systems. Upon a closer look, the graph demonstrates, however, that the results achieved are by far not comparable with the results achieved with the original control system based on agam.

- (1) The maximum steam capacity of the boiler is 160 kg/s. The graph shows the performance data between 60 and 100 kg/s or 40 to 60 % boiler load. At this low load range NO_x reduction rates above 150 mg/Nm³ have been achieved with the original control system.
- (2) The increasing NO_x, NH_4OH consumption and the low NH_3 slip is a strong indication that NH_4OH burns to NO_x.
- (3) It can easily be calculated that with 20 l/h NH_4OH under favorite conditions only approx. 6-8 mg/Nm³ NO_x can be reduced at the given boiler load of 60 %. This is the evidence that the NO_x setpoint is very close to the NO_x baseline. In addition, the straight line for NH_4OH consumption shows that the control valve was closed to minimum. The fact that the ammonia slip is very low is not surprising if there is almost no flow of reagent. The very low ammonia slip is a consequence of the flow of reagents which has almost come to a stop.

  The NO_x clean gas values were always above the NO_x setpoint of 200 mg/Nm³. Authorities would generally not accept a plant which continuously operates above the emission limits.
- (4) The Online-CFD is obviously not able to handle moderate load changes properly. The print outs of the monitor show that the injection lances were not switched to a

higher respectively cooler level in order to avoid burning the reagent to NO_x. The graph also shows that the process finally went out of control and could only be handled by stopping and restarting the SNCR again.

Similar problems were observed at decreasing loads. **Figures 28 and 29** show that the control system had to be changed from online-CFD to agam because of an excessive increase of ammonia slip.

- This phenomenon is typical for systems based on artificial intelligence and known as “mechanical schizophrenia”. Because of the high risks involved, plants with such a control system cannot be covered by insurances.

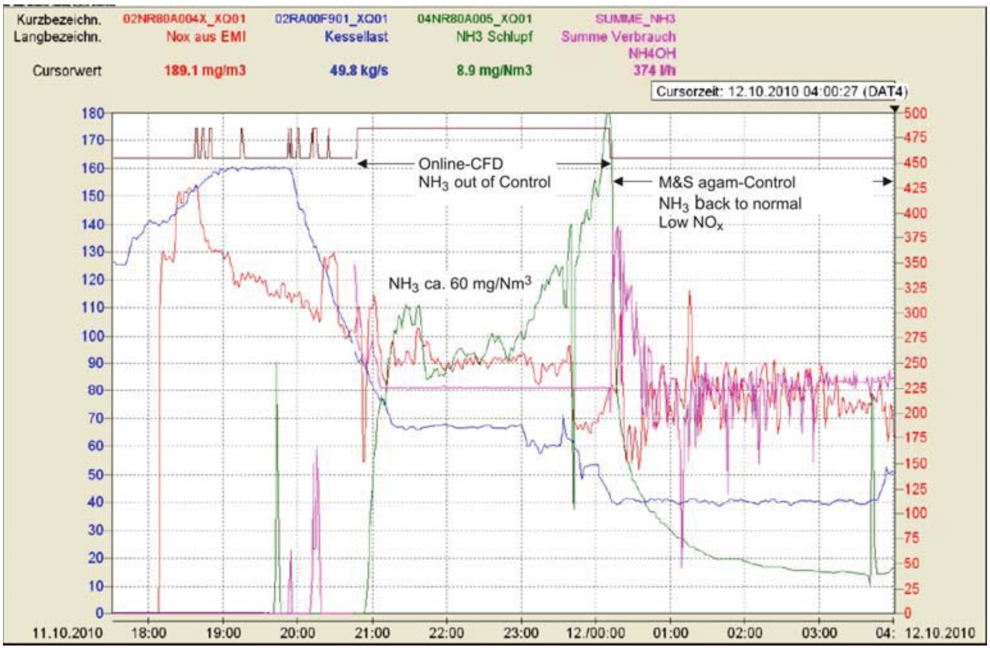


Fig. 29: Change of Control System due to Excessive Ammonia Slip

5. Summary and Outlook

The SNCR process is a reliable and economical process for NO_x reduction to meet the NO_x emission limits set by the regulators. The process has been improved continuously over the years. For several applications like waste-to-energy plants it represents already state-of-the-art. Results of new developments obtained with TWIN-NO_x and Selective Cooling of the flue gases are promising so that further improvements of the performance are expected.

Because of the low investment and operating costs of an SNCR system it could be beneficial for the owners of power plants to take a closer look at the potential of SNCR for their plant and to install pilot plants in order to find answers to the open questions.

In some Eastern European countries like Poland, Czech Republic, Romania, and Estonia decisions in favor of the SNCR technology for large power plants have been taken and several plants are operating successfully.

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.

New boilers could be designed in such a way that they meet the requirement of SNCR which is basically to leave enough space in the area of the injection levels where the temperature is best for the process. The cost involved would be negligible in comparison to the cost of the whole boiler.

The application of the SNCR technology for large power boilers still leaves open questions and not all problems are solved yet. However, the situation was not much different ten years ago for waste incinerators. Today NO_x levels < 100 mg/Nm³ are state of the art.

6. Literature

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