

# **SNCR as Best Available Technology for NO<sub>x</sub> Reduction in Grate Fired Boilers for Municipal Waste, Biomass, RDF, etc.**

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## **1. Introduction**

The integrated waste processing plant in Wijster, Netherlands, has been operating since 1996. The plant includes a sorting facility and an incineration plant. Each of the three combustion lines was originally equipped with a catalyst (SCR) for NO<sub>x</sub> reduction and oxidization of dioxins. Because of the ageing of the catalyst elements, the oxidization of dioxins had already been realized with activated carbon for some years. The catalyst elements used for denitrification would have had to be replaced as well.

Apart from the ageing of the catalysts, the high consumption of natural gas for reheating the flue gases is another negative aspect of SCR. When the plant was designed in 1992, it could not be anticipated that soon Selective Non-Catalytic Reduction (SNCR) could reach NO<sub>x</sub> levels comparable to SCR which represented the state-of-the-art technology at that time. Meanwhile, the SNCR process is also referred to as “Best Available Technology Reference” (BREF) for waste-to-energy plants by the European Commission, which shows that SNCR is a reliable, technically fully developed and economical process for NO<sub>x</sub> removal. Because of the significantly more favorable cost-benefit ratio of the SNCR technology, it was decided to close down the SCR plants in the three combustion lines and replace them with SNCR. Regardless of the economic advantages, a key factor for this decision was, of course, that emission levels would lie within or even below the limits set by the authorities.

## **2. Description of the Waste-to-Energy Incinerator before Retrofitting**

The residual waste which remains after separating bio-waste, paper, glass, textiles, plastic materials and hazardous waste is shredded and sorted. Plastic materials, paper-plastic-mixes and a fine-grained fraction are divided from the residual waste and are either placed in the market separately or fermented. The resulting fuel has a calorific value of approximately 9 MJ/t and is burnt in three lines with a capacity of 25 t/h each, equivalent to a thermal output of approx. 60 MW.

Each combustion line consists of a grate fired boiler, an electrostatic precipitator, a two-phase flue gas scrubber with a spray dryer for evaporating the waste water of the scrubbers, a device for blowing activated carbon into the flue gas duct for dioxin removal and a catalyst for selective NO<sub>x</sub> removal (**Figure 1**). The flue gases entering the SCR are reheated to the reaction temperature of approx. 210 C° by a heat exchanger using the excess heat contained in the flue

gases that leave the SCR. The additional energy needed to reheat the flue gas up to the level necessary for the reaction in the catalysts is provided by natural gas fired burners.

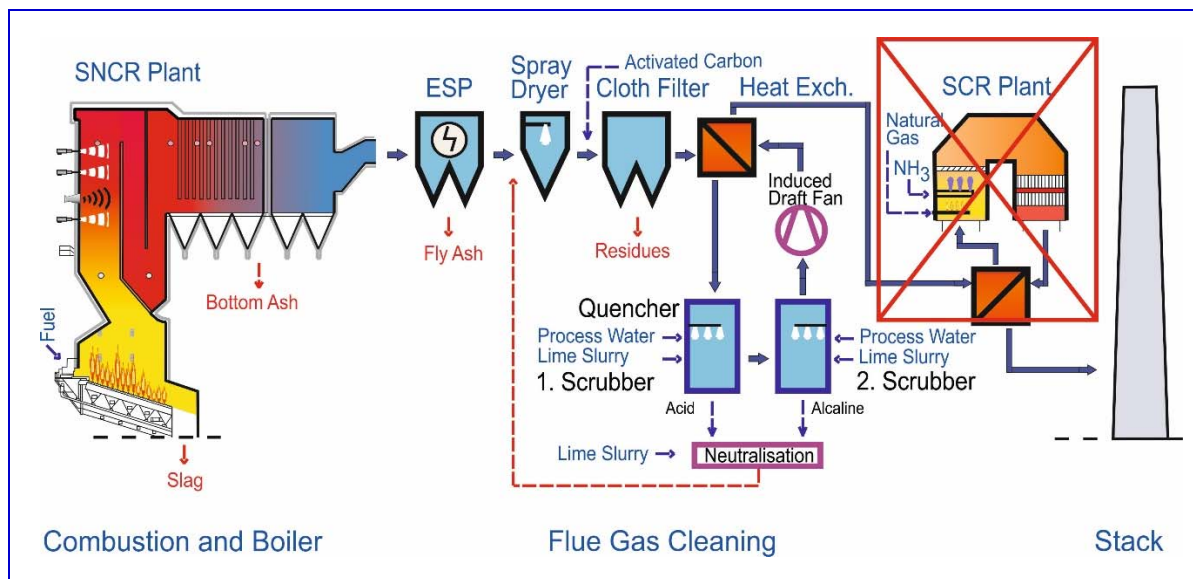


Figure 1: Waste-to-Energy Plant Wijster - Replacement of SCR by SNCR

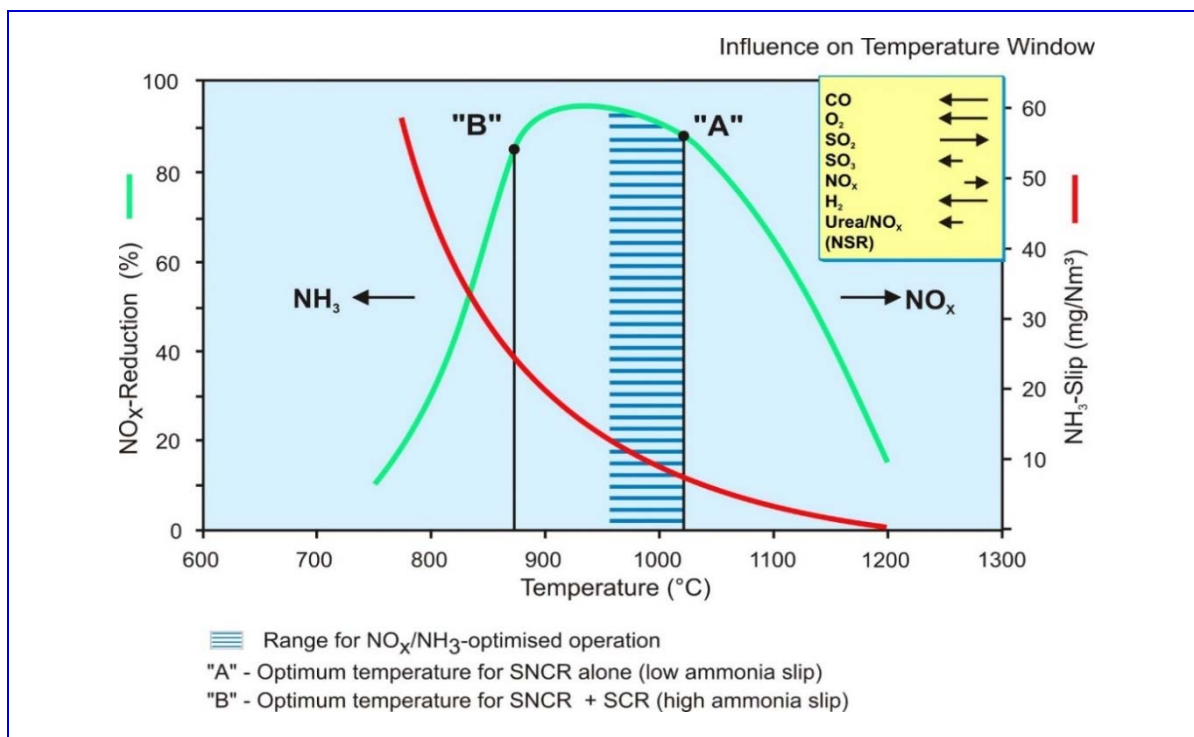
### 3. NO<sub>x</sub> Reduction after Retrofitting

#### 3.1. Basic Principles of the SNCR Process

Both technologies, Selective Catalytic Reduction (SCR) and Non-Catalytic Reduction (SNCR) of nitrogen oxides use reagents which are injected into the hot flue gases either as an aqueous solution (ammonia water, urea solution) or as gas. The chemical reaction is similar in both cases: it forms molecular nitrogen and water vapor. Depending on the flue gas composition (**Figure 2**) the optimum temperature window for the SNCR process in which a significant NO<sub>x</sub> reduction can be achieved lies between 850 and approx. 1,050 C° and is about 50 K wide. Hotter temperatures increase the oxidization of ammonia, i.e. nitrogen oxides are formed. Colder temperatures reduce the reaction time and produce NH<sub>3</sub> slip which could form ammonia salts causing secondary problems further down the flue gas path.

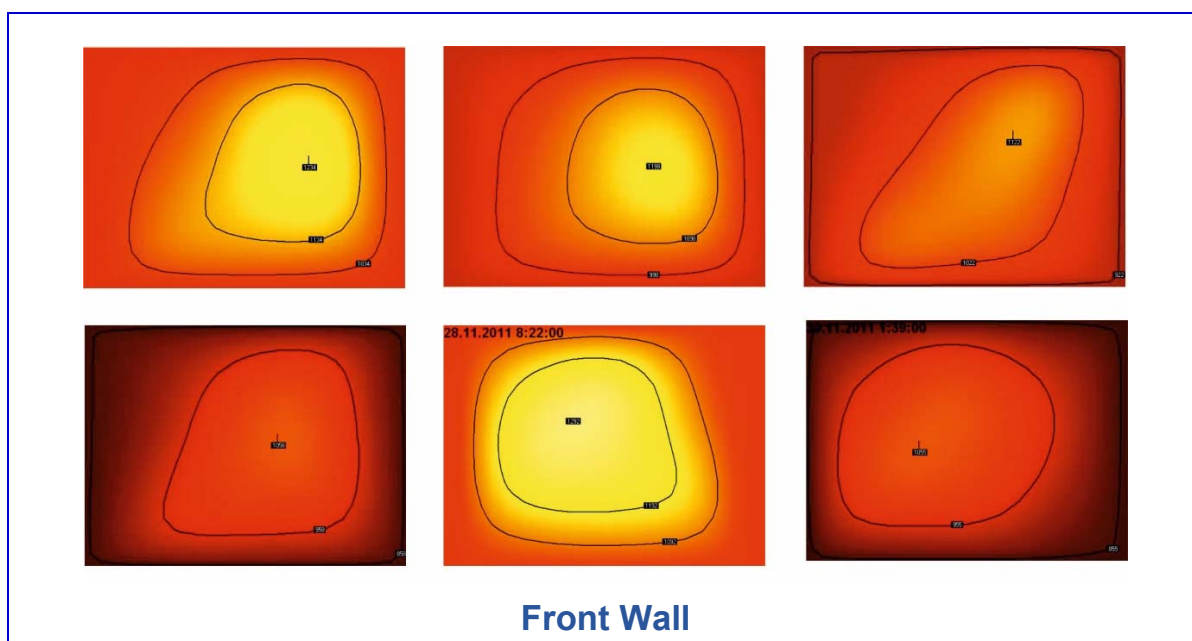
The reactions with catalysts also take place in limited temperature windows, but depending on the catalyst's composition it is located outside the furnace respectively the boiler.

To achieve the optimum NO<sub>x</sub> reduction and minimum NH<sub>3</sub> slip the reagent “only” needs to be mixed thoroughly with the flue gases under optimum temperature conditions.



**Figure 2: NO<sub>x</sub> Reduction – Influence on Temperature Window**

The constantly changing composition of waste in waste-to-energy plants causes fast and substantial variations in calorific value and ignition characteristics of the fuel. At the same boiler load, this creates large fluctuations in heat release and temperatures in the combustion system resulting in temperature imbalances of up to 150 K or even more (**Figure 3**).



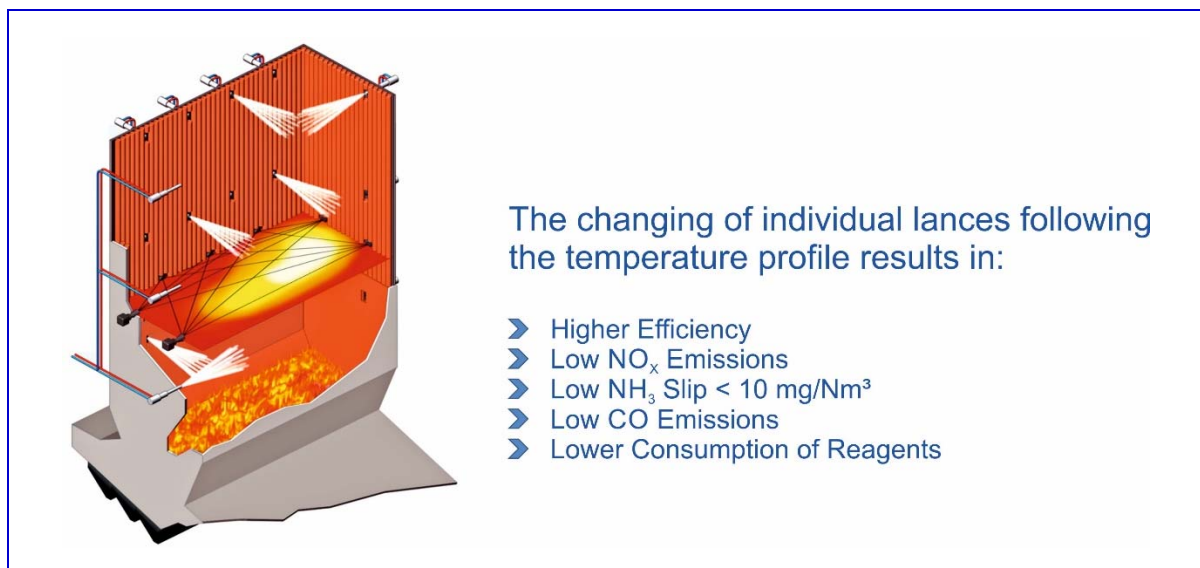
**Figure 3: Temperature Profiles in agam Measurement Level at Different Boiler Loads**

Additionally, the temperature window moves upwards in the combustion chamber respectively downstream the flue gas path, since fouling on the heating surfaces and consequently the flue gas temperatures increase during the service intervals.

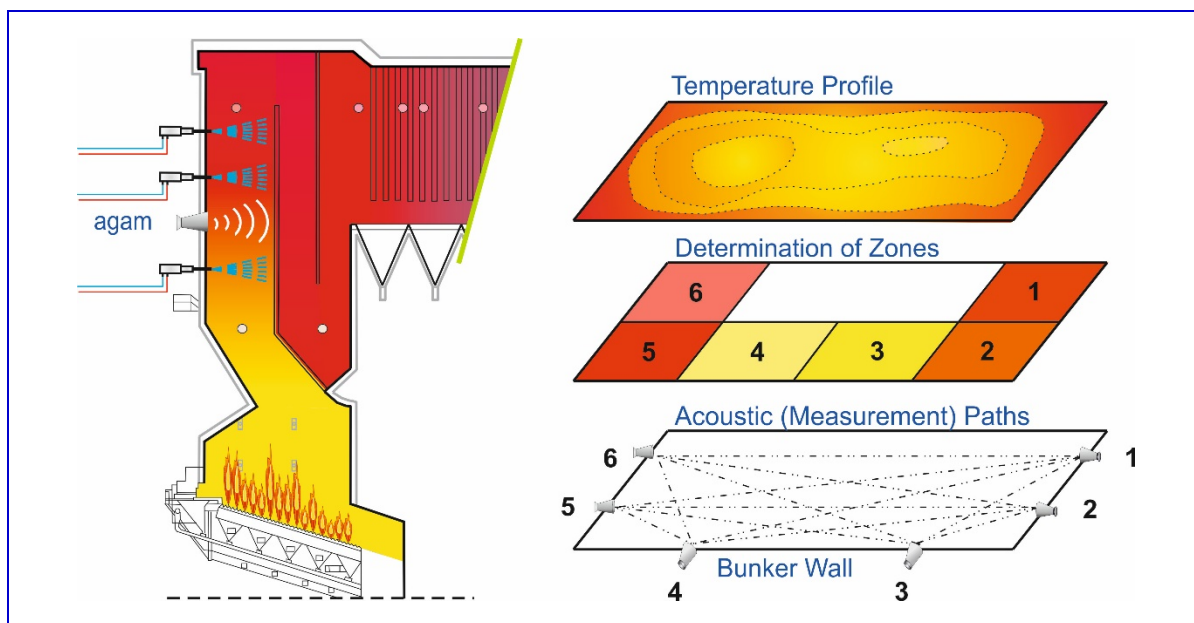
The authorities for Wijnster request an extremely low  $\text{NO}_x$  clean gas level of  $< 60 \text{ mg/Nm}^3$  (dry at 11 %  $\text{O}_2$ ) and an  $\text{NH}_3$  slip of  $< 10 \text{ mg/Nm}^3$ . To meet these requirements, each individual injection lance must inject the reagent exactly into the upper range of the temperature window of each temperature zone over the entire cross-section and under any given operating condition. Within this small temperature range of only approx. 50 K the degree of  $\text{NO}_x$  reduction is highest and  $\text{NH}_3$  slip is lowest.

This mode of operation cannot be realized reliably in standard SNCR plants which are operated with conventional methods. However, plants which have been equipped with an appropriate temperature measurement system have proven successful.

The temperature profile is divided into sections and can be assigned to individual lances or groups of lances which can be changed to another level depending on the flue gas temperature measured (**Figures 4 and 5**). This ensures that the reagent gets to the locations, which are most effective for the reaction even at rapidly varying flue gas temperatures, so that the SNCR plant always operates in the optimum range with regard to  $\text{NO}_x$  reduction,  $\text{NH}_3$  slip and reagent consumption.



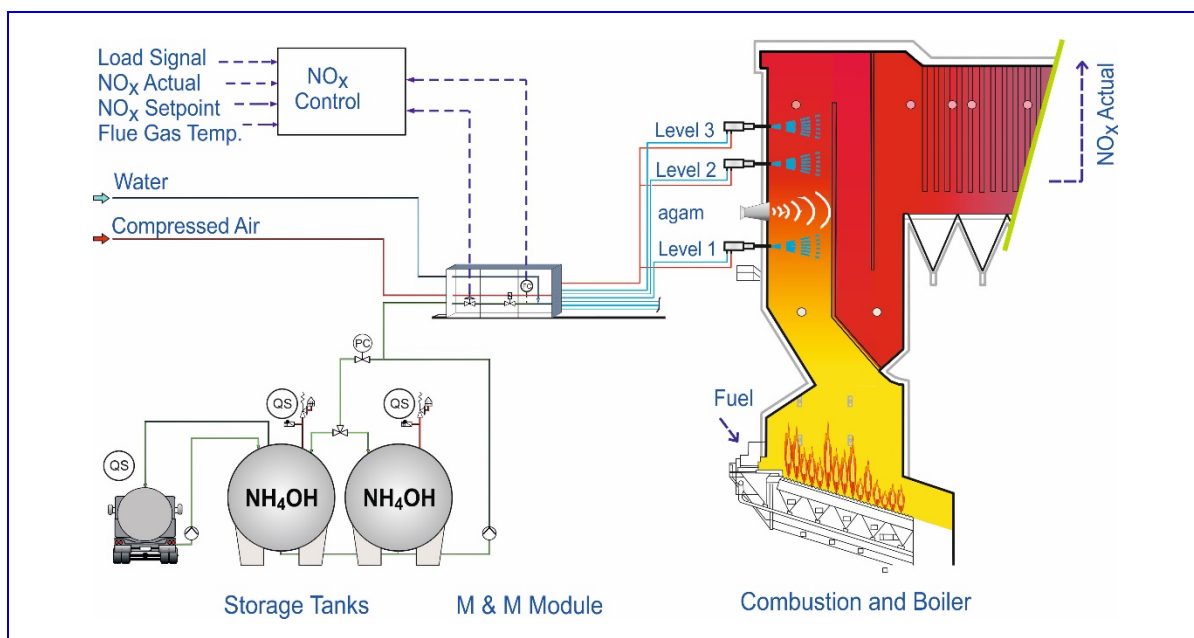
**Figure 4: Temperature Controlled Individual Lances**



**Figure 5: Temperature Measurement and Injection Levels in a Waste-to-Energy Plant in the Netherlands**

#### 4. Design and Major Components

The simplified flow chart (**Figure 6**) shows the functions and the components of the actual SNCR.



**Figure 6: Flow Chart - SNCR Plant with agam and 3 Injection Levels**

Due to the challenging requirements ( $\text{NO}_x < 60 \text{ mg/Nm}^3$  and  $\text{NH}_3 \text{ slip} < 10 \text{ mg/Nm}^3$ ), three injection levels with 6 injection lances per level have been installed. Depending on the



temperature profile each lance is controlled and switched in such a way that ammonia water is always injected into the furnace within the optimum temperature range of the flue gas for SNCR.

#### 4.1. Storage of Reagents

For storing ammonia water the existing storage facilities of the SCR plant are being used. There are two single-walled storage tanks made of GRP with a capacity of 55 m<sup>3</sup> each (**Figure 7**) which are located in a building in a leak-proof catch basin which prevents ammonia water from contaminating ground waters. The piping for the common supplies to all three lines was integrated into the existing system, adding only those fittings and alarms necessary for SNCR.

The comprehensive security equipment also includes ammonia sensors, flame arrestors, gas displacement pipe, whole body security shower, eye shower, etc.



**Figure 7: Ammonia Storage Tanks**

The storage tanks are filled from tank-trucks using an unloading pump. Since the displaced gas volume from the storage tanks may not escape into the air, the gas displacement line recovers the vapors and returns them into the tank on the delivery truck. Due to the risk of explosion, it is not allowed to use the more cost-efficient submersible pumps for pumping ammonia water

from the tank to the mixing and metering modules and the injection lances. The danger classification of ammonia water is water hazard class 2, meaning that it is dangerous to water. Furthermore, ammonia water has a high hazard potential for the environment and therefore has to comply with the European Standard EN 12952-14:2004 (formerly TRD 451 and 452).

#### 4.2. Transfer Pumps

Ammonia water is pumped from the storage tank through a circulation line and a pressure control valve directly back to the tank. A transmission line branches from the circulation line and feeds the mixing and metering modules of each of the three combustion plants.



The modules are equipped with armatures, measurement and control devices needed for measuring and controlling flow rates and pressures of reagents, compressed air and deionized water (**Figure 8**).

**Figure 8: Mixing and Metering Module and Injection Lances**

The three mixing and metering modules have the following functions:

- Measuring of flow rates (reagent, deionized water, air)
- Mixing of reagent with deionized water
- Distributing fluids and atomizing air to the injection lances
- Shutting off the supply of reagent in case of failure

The pressures of liquids and compressed air depend on the required penetration depth into the furnace and the droplet size. The pressure ranges from 2.7 – 3.4 bar at the inlet of the lances. Taking into account the pressure drop in the module and the pipelines leading to the lances, the



pressure in the mixing and metering module is about 3.4 – 3.8 bar after passing the pressure reducing valve (deionized water) respectively the control valve ( $\text{NH}_4\text{OH}$ ).

A cabinet protects all parts of the module against dust and spray water. Glass doors facilitate reading the instruments when passing by. Especially in plants operating with ammonia water, glass doors help minimize the dangers for service personnel. The risk of leakages can be judged without having to open the doors and without having to expose anyone to toxic vapors.

Mixing and metering modules operating with ammonia water are subject to more stringent security standards than urea solution. Piping and fittings have to comply with the pressure rating PN10. All materials and fittings which come into contact with ammonia water need a 3.1 certificate. To prevent any dangers resulting from leakages, there are ammonia detectors which activate a security alarm at 400 ppm ammonia and stop the pumps at 800 ppm.



**Figure 9: Control Room**

All controls for the SNCR plant were integrated into the existing central process control unit in the control room. Therefore, no decentralized controls were needed for any of the three lines (Figure 9).

### 4.3. Injection System



In order to achieve the best denitrification results, the nozzles are specifically designed, taking into account boiler geometry, flue gas conditions, velocity and size of the droplets. Each lance tip has a nozzle which secures an even distribution of the water soluble reagents in the flue gas. Due to its easy handling, compressed air is the preferred driving agent. To dilute ammonia water, it is absolutely necessary to use deionized as a carrier medium, because otherwise calcium deposits may block fittings and nozzles within just one day (**Figure 10**).

**Figure 10: Injection Lances and agam**

With the wall-mounted lances used in Wijster, the wear caused by heat and aggressive components in the flue gas is minimized.

## 5. Operating Experience and Secondary Emissions

Thorough planning of all works and the correct positioning of the injection levels were the keys to assure an operation without major incidents from the beginning. As flue gas reached “normal” temperatures soon after the re-commissioning of each boiler, also  $\text{NH}_3$  slip stayed within the specified limits after start-up. Usually, it takes a waste-to-energy boiler about 2 – 4 weeks to reach the basic fouling which is needed to reduce the heat transfer to the membrane walls and keep the flue gas temperatures high enough for optimum  $\text{NO}_x$ -reduction.

The results of the first months of operation are listed in **Tables 1 and 2**. Data collected from the first line were extrapolated to all three lines.

In order to minimize NH<sub>3</sub> slip, the reagent has been injected into the hot area of the temperature window to the right of point “A” in **Figure 2** where an increasing proportion of ammonia was oxidized to NO<sub>x</sub>. Since regular operations show that almost all of the ammonia slip in the flue gases downstream the boiler is absorbed in the wet scrubber, the NH<sub>3</sub> limits at stack are kept, even with an increased NH<sub>3</sub> slip.

Emissions	Unit	Limit	Operation In 3 Plants
NO <sub>x</sub> daily average*	mg/Nm <sup>3</sup>	100	23-84
NO <sub>x</sub> annual average*	mg/Nm <sup>3</sup>	65	50
NH <sub>3</sub> daily average downstream the boiler*	mg/Nm <sup>3</sup>		15 to >22
NH <sub>3</sub> daily average* at stack	mg/Nm <sup>3</sup>	3	0,18

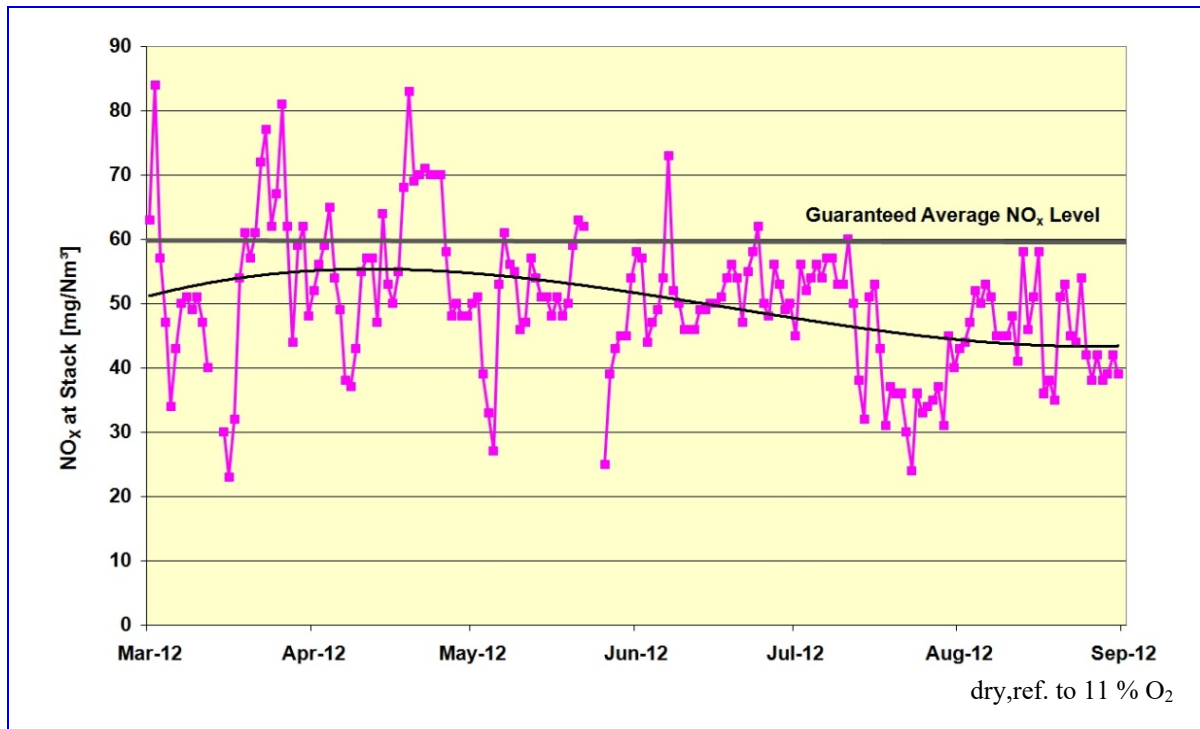
\*dry, ref. to 11 % O<sub>2</sub>

**Table 1: Emission Levels with SNCR Plant**

Operating Data	Unit	SCR NH <sub>4</sub> OH (24.5 %)	SNCR NH <sub>4</sub> OH (24.5 %)
Throughput of waste	t/h	25	25
Flue gas volume flow	Nm <sup>3</sup> /h, tr.	100,000	100,000
Operating hours	h/a	8,000	8,000
NO <sub>x</sub> raw gas concentration	mg/Nm <sup>3</sup>	330	330
NO <sub>x</sub> clean gas concentration	mg/Nm <sup>3</sup>	45	50
NO <sub>x</sub> reduction per line	kg/h	28.5	28
NO <sub>x</sub> reduction (three lines)	t/a	684	672
Ammonia water 24.5 % (three lines)	t/a	800	4,000
CO <sub>2</sub> (three lines) for additional energy	t/a	12,000	
Consumption of compressed air incl. agam	Nm <sup>3</sup> /h		500
Consumption of deionized water	m <sup>3</sup> /h		1.2
Additional consumption by suction draught	MWh/a	6,100	
Consumption of natural gas	Nm <sup>3</sup> /a	6,600,000	

**Table 2: Operating Data - SCR versus SNCR (per Line) in Wijster**

The daily NO<sub>x</sub> averages in **Figure 11** demonstrate that the required emission levels are always met. During the first nine months an annual NO<sub>x</sub> average of 50 mg/Nm<sup>3</sup> (dry at 11 % O<sub>2</sub>) was obtained. This is comparable to the SCR plant which reached an annual NO<sub>x</sub> value of 45 mg/Nm<sup>3</sup>. The daily NO<sub>x</sub> average varied frequently during the optimization phase, but lies now below the emission level of 65 mg/Nm<sup>3</sup>, approved by the authorities.

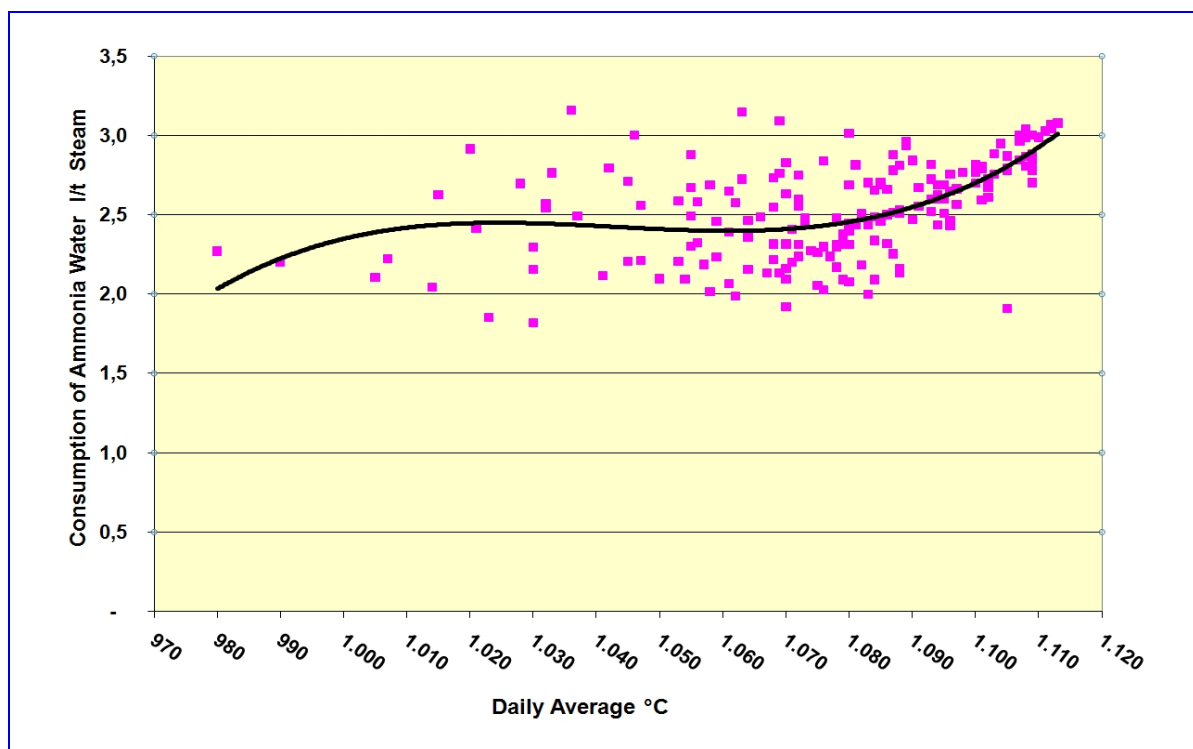


**Figure 11: Daily NO<sub>x</sub> Averages Line 11 – March to September 2012**

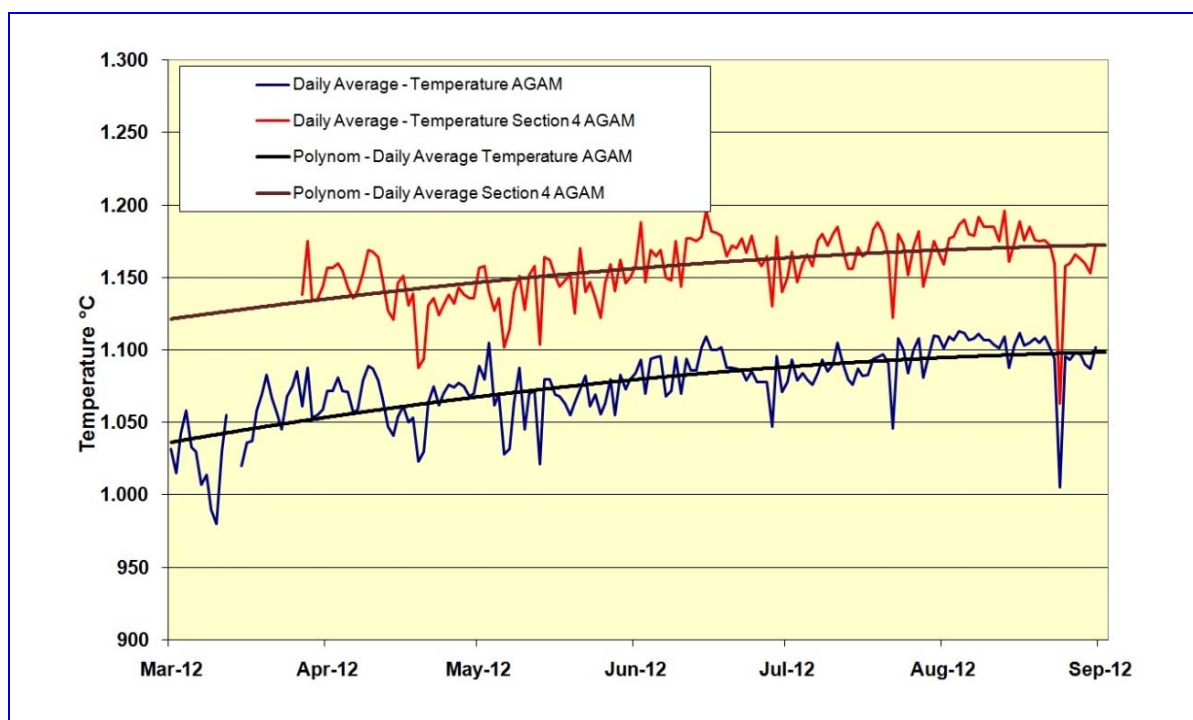
The specific ammonia water consumption increases significantly with the rising flue gas temperatures in the boiler. When the boiler was commissioned after revision in March 2012 it was completely clean. Within a few weeks of operation, the flue gas temperature rose significantly due to the fouling of the heat exchangers. **Figure 12** shows how the ammonia water consumption increases, depending on the rising average flue gas temperature of approx. 100K between two service intervals. The highest temperature is measured in section 4 (refer to **Figure 3**). Here, the highest proportion of NH<sub>3</sub> is burnt to NO<sub>x</sub> since temperatures in this section lie approx. 75 °C above the average temperature of the furnace cross-section.

In order to optimize the efficiency of the SNCR plant with regard to the consumption of ammonia water more reagent is now injected between points “A” and point “B” of the temperature window. For this reason an additional level of openings has been installed in each

boiler where the highest level of injectors will be shifted when the flue gas temperatures are high because of fouling at the end of each service interval (**Figure 13**).



**Figure 12: Variations in Specific Ammonia Water Consumption**



**Figure 13: Increase of Average Temperatures between two Service Intervals**



### **5.1. Contamination of By-Products from Flue Gas Cleaning System by Ammonia**

During the design phase it was expected that  $\text{NH}_3$  slip from the SNCR plant would be absorbed in the wet scrubber and return to the circuit with the waste water. In order to prevent the accumulation of  $\text{NH}_3$  slip, the installation of an  $\text{NH}_3$ -stripper was considered necessary for separating ammonia from the waste water of flue gas cleaning system. However, operating experience shows that the  $\text{NH}_3$ -concentration in the by-products is within acceptable limits at all three lines.

Therefore, an ammonia stripper is not needed, even if all three SNCR plants operate simultaneously. The contamination of the by-products of flue gas cleaning with ammonium salts does not exceed the limits. Therefore, no changes need to be made with regard to waste disposal.

## **6. Availability**

The availability of the overall waste-to energy plant is hardly affected by the SNCR. All relevant components like pumps which could have an influence are redundant. The injectors which come into contact with the flue gas are spare and wear parts and have to be inspected and maintained at regular intervals. The inspection of the lances can be done easily during operation and if needed they can be exchanged. If the lances are changed during operation it should be done one after the other in order to keep the half-hourly averages of  $\text{NO}_x$ . It is possible to refurbish the used lances by shortening them or by exchanging the protection tubes of the lances. The nozzles have to be replaced as well, but at a longer interval than the protection tubes.

If the SNCR-plant is serviced regularly at the scheduled downtimes, the instruments in use are unlikely to be damaged. If, however, an unexpected damage does occur it can be handled during operation in nearly all events, like replacing flow meters and pressure gauges. More critical in this respect are the control valves. But as these are equipped with a bypass, it is still possible to control the flow of the reagent manually while the valve is being replaced or repaired. Careful planning of spare and wear parts stocks, as much as custom maintenance during regular downtimes will help to prevent and / or minimize almost any problem during operation.

In the unlikely event of an unscheduled downtime of the SNCR plant, the solving of any problem would take only little time that the daily averages would not be affected even then.

When using ammonia water as reagent, calcium deposits on piping, fittings and injection lances can only be prevented by using deionized water or VE-water as carrier-medium. Normal process water is sufficient for urea solution, if it contains an appropriate additive like NOxAMID. **(Figure 14)**



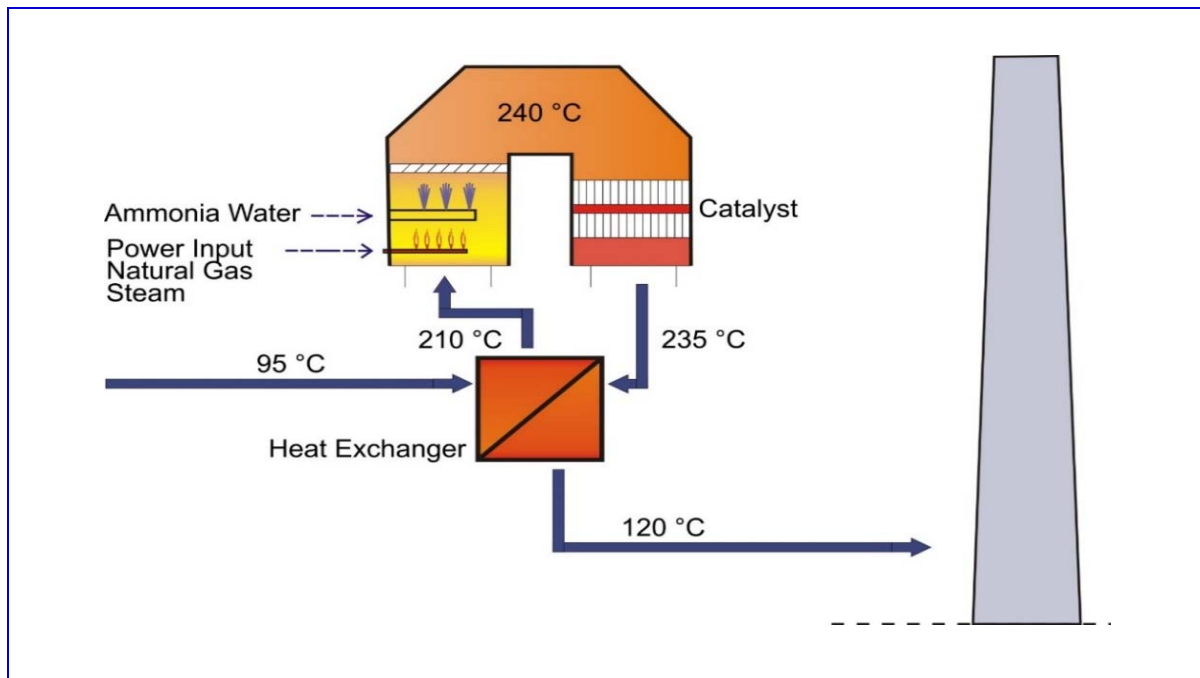
**Figure 14: Deposits Caused by Lime Precipitation**

The removal of deposits can be a very time-consuming procedure which may have a substantial impact on the overall plant's availability. Therefore, it is mandatory to use the appropriate reagent and dilution water.

## **7. Comparing SCR to SCNR under Energy and Environmental Aspects**

The SCR plant in Wijster was installed downstream a wet flue gas cleaning system outlined in the simplified flow-chart of **Figure 15**. The pressure drop across the heat exchangers, the mixer, the flue gas ducts and the catalyst elements is approx. 25 mbar. To overcome the pressure drop, a blower with a consumption of 250 kW per combustion line is required, whereas this additional energy is not needed in an SNCR plant. The temperature loss of the flue gas is approx. 30 K. The power required to raise the temperature again, is provided by gas burners consuming 2,200,000 m<sup>3</sup>/a natural gas per plant for this purpose. After removing the three catalysts the flue gas temperature at the stack decreased from 150 °C to approx. 95 °C.

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



**Figure 15: Flow-Chart - SCR Plant after Flue Gas Reduction**

Also from the environmental point of view the SNCR technology appears in a positive light: Consuming less energy also means reducing emissions like CO<sub>2</sub> while the NO<sub>x</sub> emissions with SNCR are on the same level as with SCR.

As opposed to that, an SCR plant produces additional emissions of 15,000 t/h CO<sub>2</sub> because it consumes a lot of additional energy for the generation of electricity which is needed for the higher blower capacity and for the gas fired duct burners.

Operating costs for reducing 1 ton of NO<sub>x</sub> are by far higher when using SCR technology than they would be in an SNCR plant. From other studies it can be concluded that the investment for SCR is at least 5 times higher than for SNCR. Considering its better cost-benefit ratio, environmental protection could be much more effective, if 5 SNCR systems were installed instead one SCR plant. **Table 3** summarizes the comparison between the two technologies.

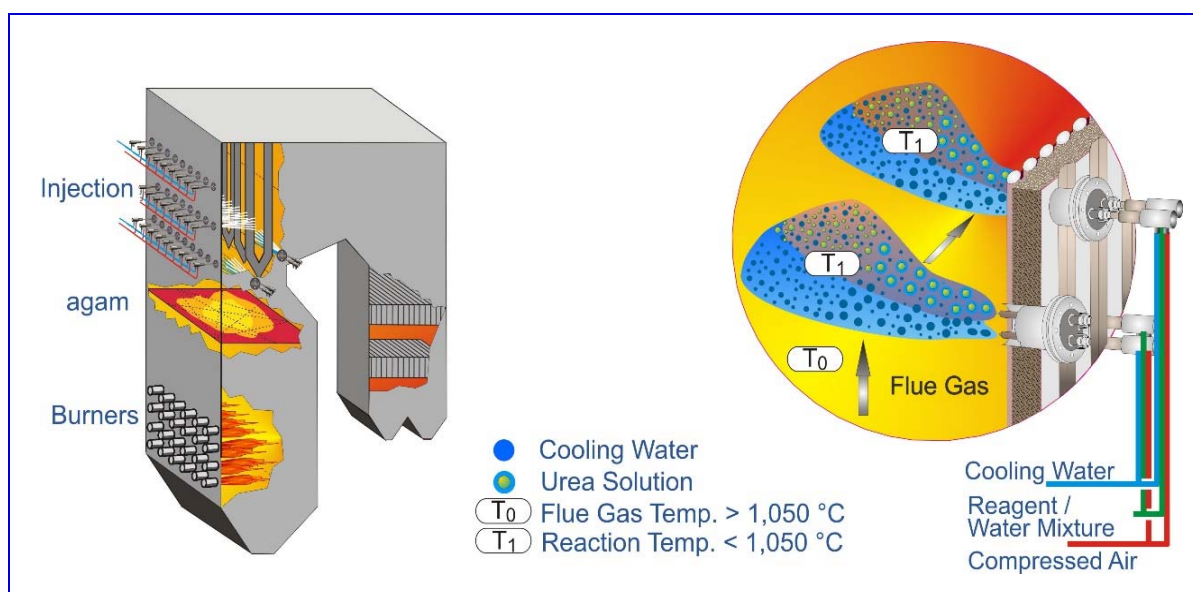
SCR	SNCR
Comparable NO <sub>x</sub> clean gas values (45 mg/Nm <sup>3</sup> )	Comparable NO <sub>x</sub> clean gas values (50 mg/Nm <sup>3</sup> )
Additional power consumption due to pressure drop in the catalyst, mixer, heat exchangers, flue gas ducts	Occasional contamination of fly ash or other by-products of flue gas cleaning with ammonia
Additional power consumption for heating the flue gases	Additional consumption of compressed air, deionized water and reagent
Negative effects on availability of the overall plant	No effect on availability, redundancy of all components critical to operation
Capital investment– approximately 5 to 10 times higher than for SNCR	Low investment
High operating costs	Low operating costs
High maintenance costs	Minimum maintenance requirements

**Table 3: Comparison - SCR versus SNCR**

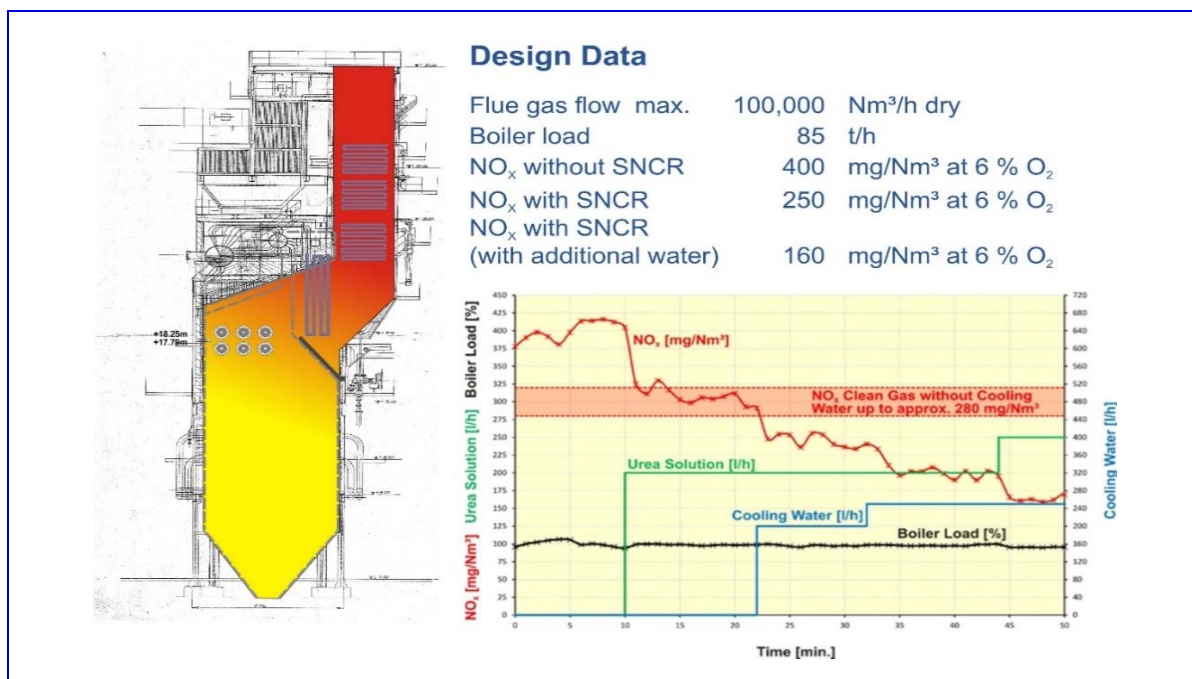
## 8. Most Recent Developments of NO<sub>x</sub> Reduction with SNCR

### 8.1. Selective Cooling of Flue Gases

One of the solutions to provide better operating conditions is to cool down the flue gases to a level where NO<sub>x</sub> reduction is possible when the flue gas is too hot. “Selective Cooling” (**Figure 16**) is a method which requires an additional injection level for cooling water below the upper injection level.



**Figure 16: Selective Flue Gas Cooling for coal-fired boilers**



**Figure 17: Selective Cooling - Retrofitting of an SNCR plant operated with urea solution**

This method reacts to temperature imbalances in a way that cooling water is injected only in those areas which are too hot. Individual lances or groups of lances are activated depending on the temperature profile generated by a suitable temperature measurement system.

**Figure 17** shows the results of the Selective Cooling in a coal-fired boiler in the Czech Republic. With additional cooling water alone, the NO<sub>x</sub> reduction of the SNCR is increased by an additional 120 mg/Nm<sup>3</sup> to a level of < 160 mg/Nm<sup>3</sup>.

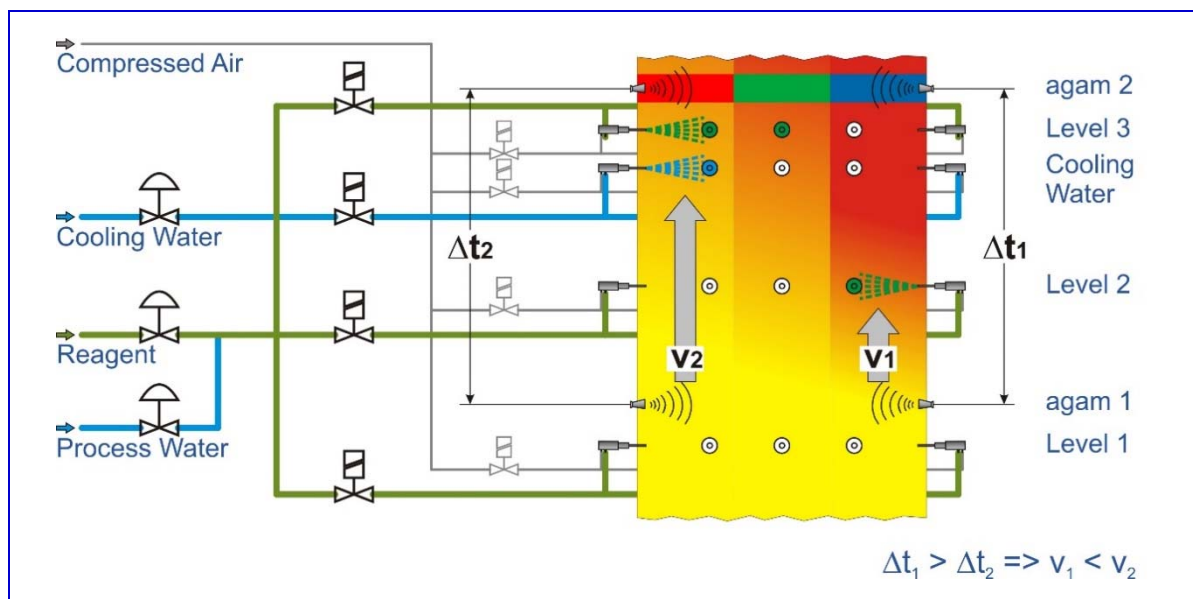
## 8.2. Adaptive Flue Gas Cooling

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 in the furnace (**Figure 18**).





**Figure 18: Principle of Adaptive Flue Gas Cooling**

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<sub>x</sub> reduction and low ammonia slip. Furthermore, the activation of the lances for reagent can be determined more precisely when temperatures are measured in two levels.

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

## 9. Summary and Outlook

The results of several years of operation show that SNCR technology can reach comparably low NO<sub>x</sub> emission levels as with SCR. These achievements could be realized essentially by combining SNCR with an advanced temperature measurement system and the control and switching of individual lances.

Because of the chemical conditions in the SNCR process, the consumption of ammonia water is higher than with SCR, but this effect is by far compensated since neither the natural gas for reheating – 6.6 million m<sup>3</sup> per year – nor the power for re-circulating the flue gases is needed any more. This reduces the emissions of CO<sub>2</sub> considerably as well. Consequently, SNCR technology compares positively to SCR and is certainly the better technical solution for the environment. The retrofitting of the waste-to-energy plant Wijster has improved its energy efficiency considerably.

Taking into account all the savings as opposed to the operating costs for the catalysts which have been shut down, there is only one possible conclusion: The retrofitting of the three combustion lines in Wijster from SCR to SCNR is a full success.

Furthermore, the SNCR process has been continuously developed and improved over the last years. It has reached a high technological standard and has widely found acceptance in the meantime, especially with regard to NO<sub>x</sub> reduction in the flue gas of small to medium sized combustion plants burning for example waste, refuse derived fuel, and biomass.

Depending on the design of the plant it is possible to maintain emission limits of < 100 mg/Nm<sup>3</sup> NO<sub>x</sub> in clean gas and NH<sub>3</sub> slip < 10 mg/Nm<sup>3</sup>. Particularly when taking into account the cost-benefit ratio, the SNCR technology has been well-established and accepted as Best Available Technology (BAT) for NO<sub>x</sub> reduction.

Currently, there is an increasing demand for plants that have boilers with an output of 300 to 500 MW<sub>el</sub> and emission levels of < 150 mg/Nm<sup>3</sup> and NH<sub>3</sub> slip < 5mg/Nm<sup>3</sup>.

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