Replacement of an SCR DeNO$_x$ System by a Highly Efficient SNCR in a Waste-to-Energy Plant in the Netherlands

Presented at VGB Workshop “Flue Gas Cleaning”

Rotterdam, 15 – 16 May, 2013

Frans Moorman,
Senior Project Manager
Attero - energiek met milieu
Wijster, Netherlands

Bernd von der Heide
Managing Director
Mehldau & Steinfath Umwelttechnik GmbH
Essen, Germany

Claus Stubenhöfer
Senior Project Manager
Mehldau & Steinfath Umwelttechnik GmbH
Essen, Germany

Contents

1. Introduction

Attero has been operating an integrated waste processing plant in Wijster, Netherlands, 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 NOx reduction. However, in this plant the catalysts have two functions: denitrification of flue gases and oxidization of dioxins.

Because of the ageing of the catalyst elements, the oxidization of dioxins has already been realized with active carbon for some years. Within the next 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_x levels comparable to SCR which represented the state-of-the-art technology at that time. Meanwhile, the SNCR process is referred to by the European Commission as “Best Available Technology Reference” (BREF) for waste-to-energy plants. Hence, SNCR is acknowledged as generally reliable, technically fully developed and as an economical process for NO_x removal.

Because of the significantly more favorable cost-benefit ratio of the SNCR technology, Attero decided to close down the SCR-plants in the three combustion lines and replaced 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_x removal (**Figure 1**). The flue gases entering the SCR are reheated to a temperature of approx. 210 C° by a heat exchanger using the excess heat contained in the flue gases leaving 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.

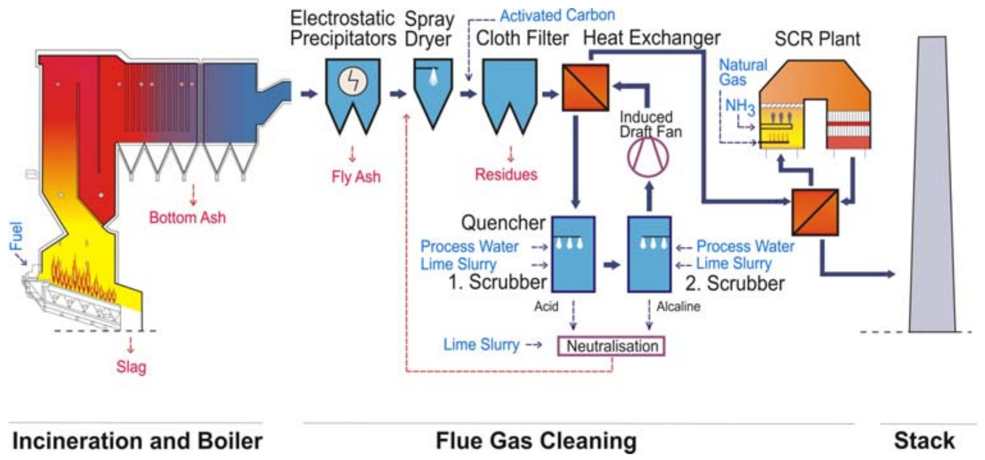


Figure 1: Diagram of the Combustion Lines with SCR

3. NO_x Reduction after Retrofitting

3.1. Basic Principles of the SNCR Process

Both technologies, Selective Catalytic Reduction (SCR) and Non-Catalytic Reduction (SNCR) of nitrogens 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 oxide and water vapor. Depending on the flue gas composition, the optimum temperature window for the SNCR process lies between 850 and approx. 1,050 C°. This is the temperature range in which a significant NO_x reduction can be achieved. Hotter temperatures increase the oxidization of ammonia water, i.e. nitrogen oxides are formed (**Figure 2**). Colder temperatures reduce the reaction time and produce NH_3 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_x reduction and minimum NH_3 slip the reagent "only" needs to be mixed thoroughly with the flue gases under optimum temperature conditions.

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. Additionally, the temperature window moves upwards in the combustion chamber respectively downstream since fouling on the heating surfaces and consequently the flue gas temperatures increase during the service intervals (**Figure 3**).

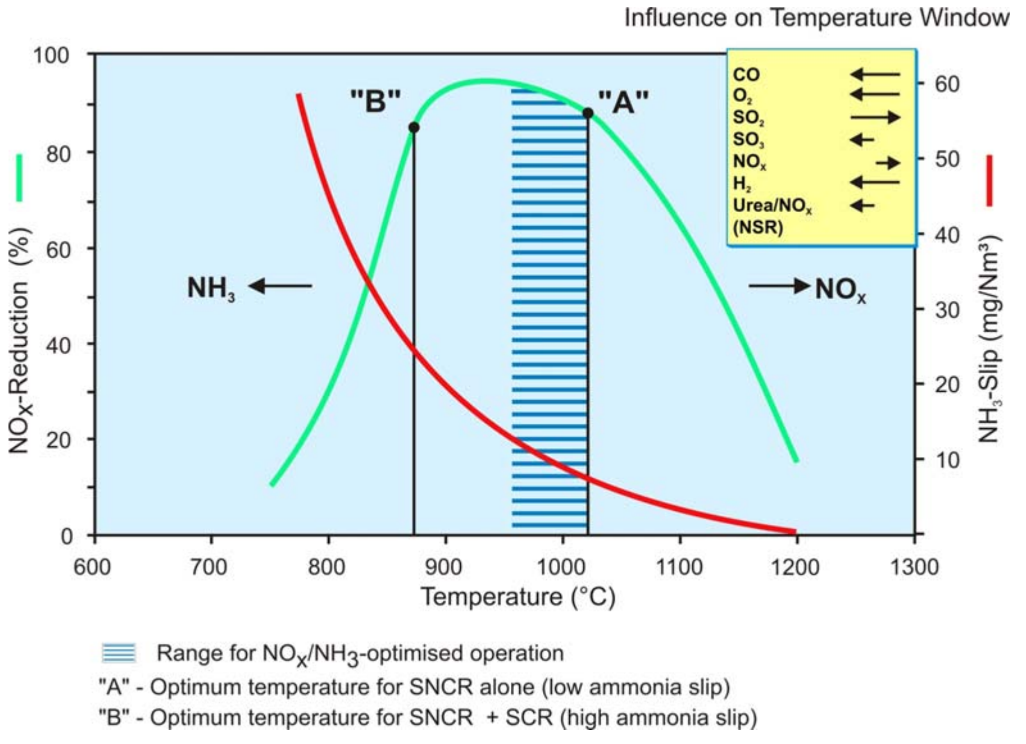


Figure 2: NO_X Reduction – Influence on Temperature Window

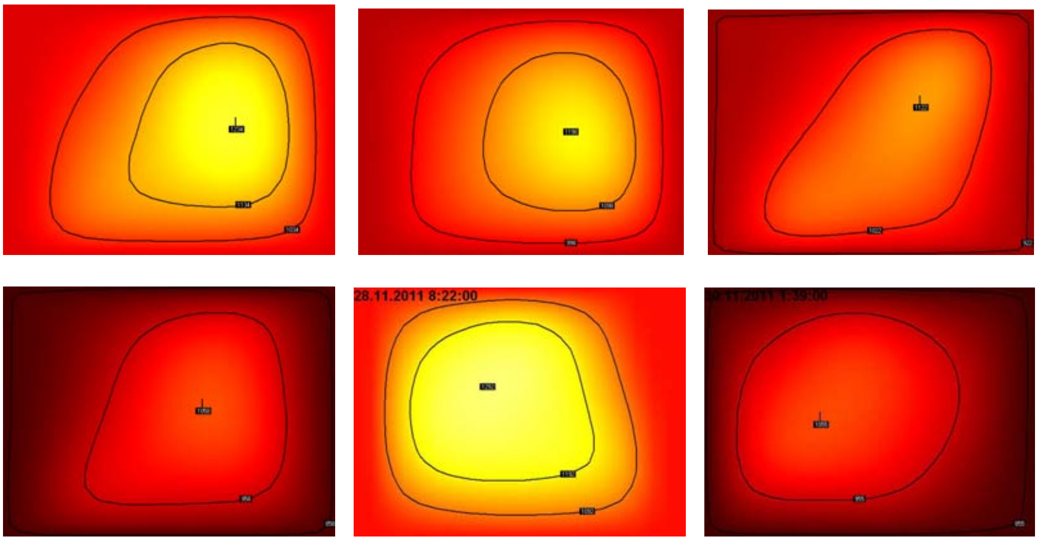
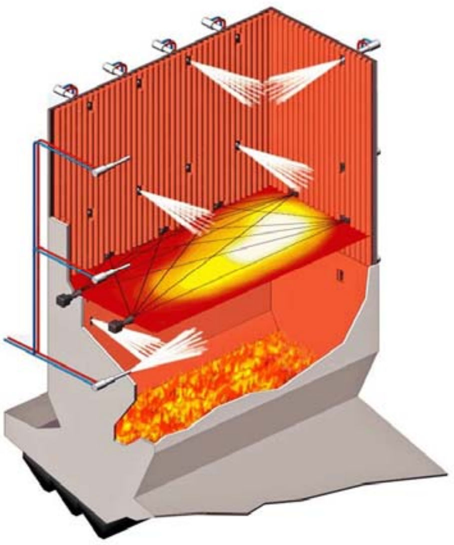


Figure 3: Temperature Profiles in agam Measurement Level at Different Boiler Loads

In order to ensure the guaranteed NO_x clean gas value of 60 mg/Nm³ (dry at 11 % O_2) and an NH_3 slip of < 10 mg/Nm³, the reagent must be injected by each injection lance exactly into the upper range of the temperature window over the entire cross-section and under any given operating condition. Within this small temperature range of only approx. 50 K (marked in **Figure 2**) the degree of NO_x reduction is highest and NH_3 slip is lowest.



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

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

Figure 4: Temperature Controlled Individual Lances

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 acoustic temperature measurement system (agam) have proven successful since each injection lance is controlled individually. Depending on the temperature the lances are switched on and off to make sure the reagent is always injected into the location with optimum temperature (**Figure 4**).

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. 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 the transmitter side and on the receiver side.

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

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 **(Figure 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 NO_x reduction, NH_3 slip and reagent consumption**.**

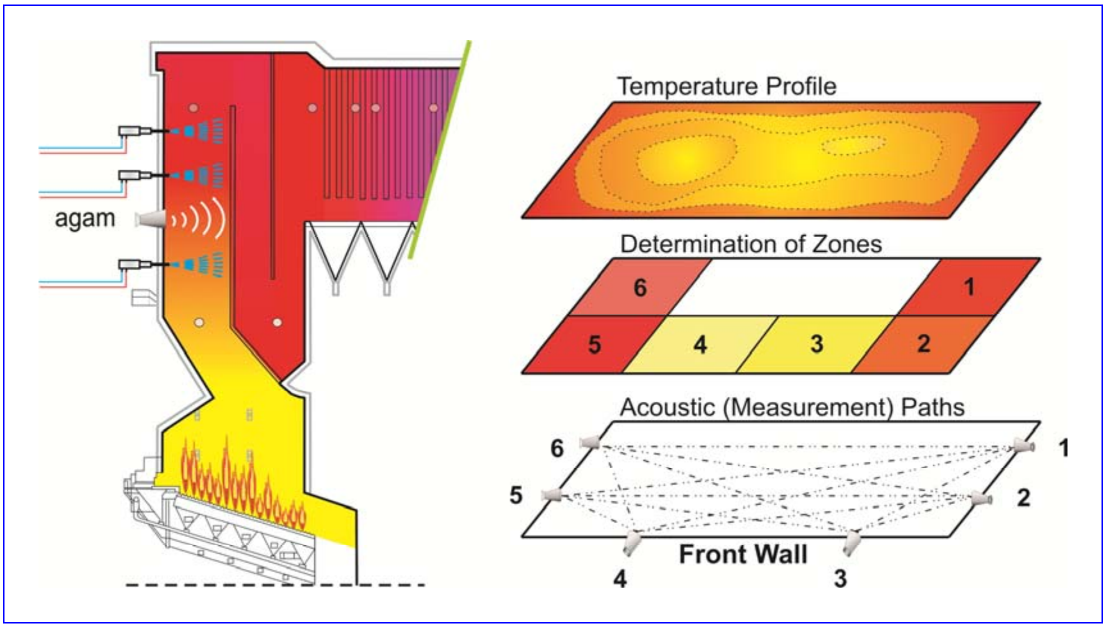


Figure 5: Temperature Measurement and Injection Levels in a Waste-to-Energy Plant in the Netherlands

3.2. Determining the Correct Position of Injection Levels

Over a period of four weeks, temperature measurements were performed at each of the three levels with a mobile acoustic temperature measurement system (agam) in order to measure the temperature distribution and temperature imbalances at different boiler loads.

For the measurements six transceivers were mounted at a height of approx. 40 m and two at 45 m. Apart from the temperature profile, this arrangement also provided reliable information on the temperature gradient between the two levels. The measurements were taken between October 2011 and January 2012. The results indicated that each of the three combustion lines would need three injection levels for the load ranges they were operated in.

The control accuracy deviates by approx. +/- 3 % from the actual steam production. The temperature gradient of each of the three boilers amounts to around 20 K / m.

During the design phase of retrofitting the plant with SNCR, the question arose if the treatment of waste water from the scrubbers would require a stripper to capture NH_3 slip or not. To be on the safe side, this component had already been included in the budget.

3.3. Plant Design and Project Implementation

In March 2012, the catalyst of the first line was shut down and was replaced by the first of three SCNR plants. The plant design after retrofitting to SNCR is shown in **Figure 6**.

The consumables ammonia water, deionized water, compressed air and control air which are needed for the new SNCR plants were already available on site. Only for ammonia water and deionized water a new pumping module was installed.

The complete retrofitting of boiler 11, including the placement of openings for the injection lances, the mounting of the transceivers for acoustic temperature measurement, installation of mixing and metering modules, control cabinets, piping and cabling, was executed during a scheduled boiler maintenance shut-down in January and February 2012. Installation works for the two remaining lines had almost been completed before the shut-down of boiler 12 in October / November 2012.

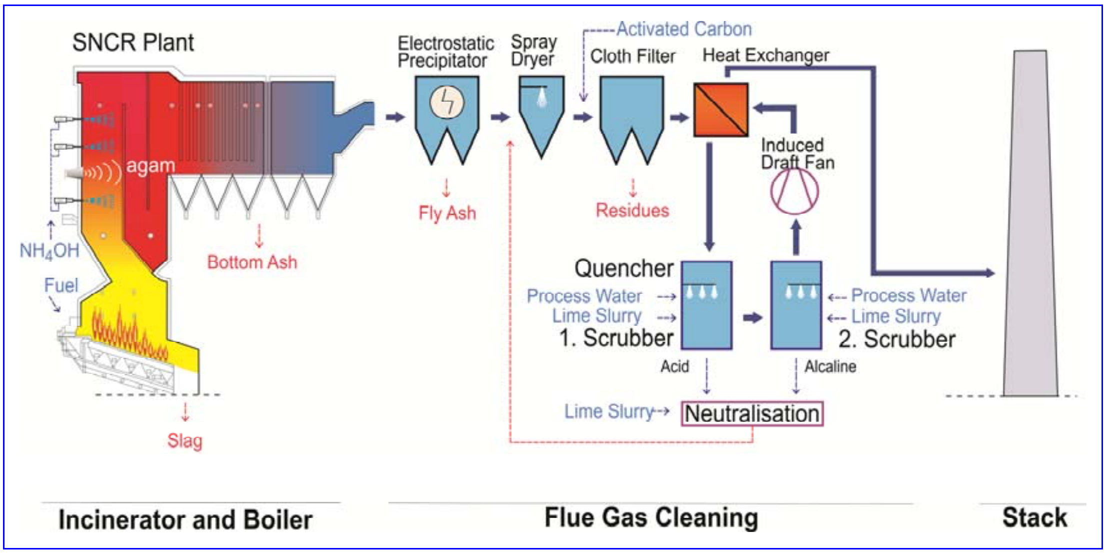


Figure 6: Diagram of Combustion Lines after Retrofitting with SNCR

Bending out of boiler tubes was only required for the acoustic temperature measurement, while the openings for the injection lances were drilled into the membrane wall between the boiler tubes.

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.

The catalysts were decommissioned in two steps: At first, each catalyst was equipped with a bypass preventing the flue gases to flow through the catalyst when the plants were started up again. The second step was to shut down and dismantle the catalysts.

4. Design and Major Components

The simplified flow chart (**Figure 7**) shows the functions and the components of the SNCR which was designed, delivered and commissioned. Due to the challenging requirements (NO_x< 60 mg/Nm³ and NH_3 slip < 10 mg/Nm³), three injection levels with 6 injection lances per level have been installed. Depending on the zone temperature 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.

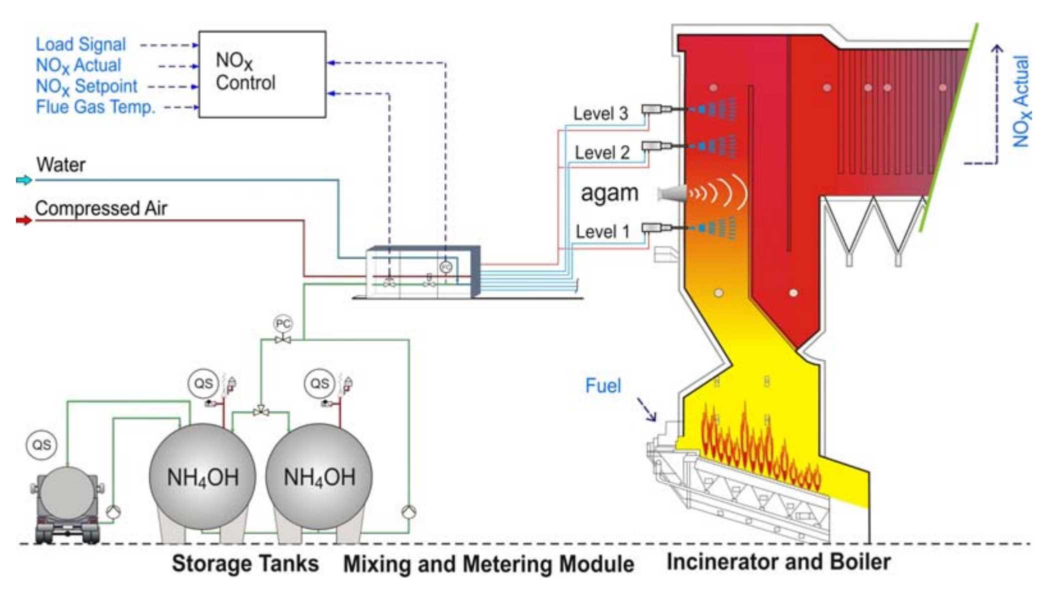


Figure 7: Flow Chart - SNCR Plant with agam and 3 Injection Levels

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 m³ each (**Figure 9**) 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.

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 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
- Shut-off of the supply of reagent in case of failure

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**).

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 (NH_4OH).

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.

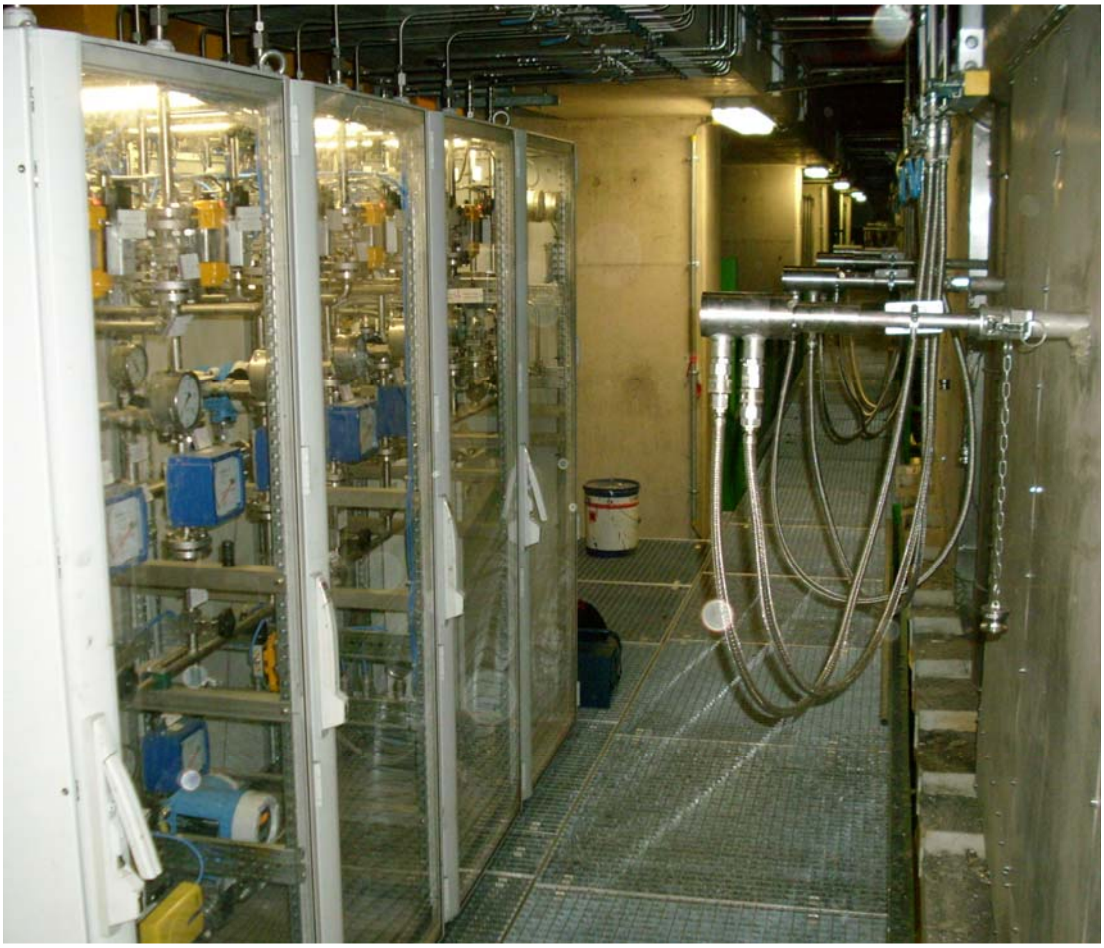


Figure 8: Mixing and Metering Module and Injection Lances

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 houses 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 water or VE-water as a carrier medium, because otherwise calcium deposits may block fittings and nozzles within just one day.

With the wall-mounted lances used in Wijster, the wear as a result of corrosion by the flue gases 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 troubles right from the start. As flue gas reached “normal” temperatures soon after the re-commissioning of each boiler, also 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.

Emissions	**Unit**	**Limit**	**Operations In 3 Plant**
NO_X daily average*	mg/Nm³	100	23-84
NO_X annual average*	mg/Nm³	65	50
NH_3 daily average downstream the boiler*	mg/Nm³		15 to >22
NH_3 daily average* at stack	mg/Nm³	3	0,18

*dry, ref. to 11 % O_2

Tab. 1: Emission Levels with SNCR Plant

The results of the first months of operation are listed in **Table 1 and Table 2 (**refer to **Chapter 7).** Data collected from the first line during the period March to September 2012 were extrapolated to all three lines.

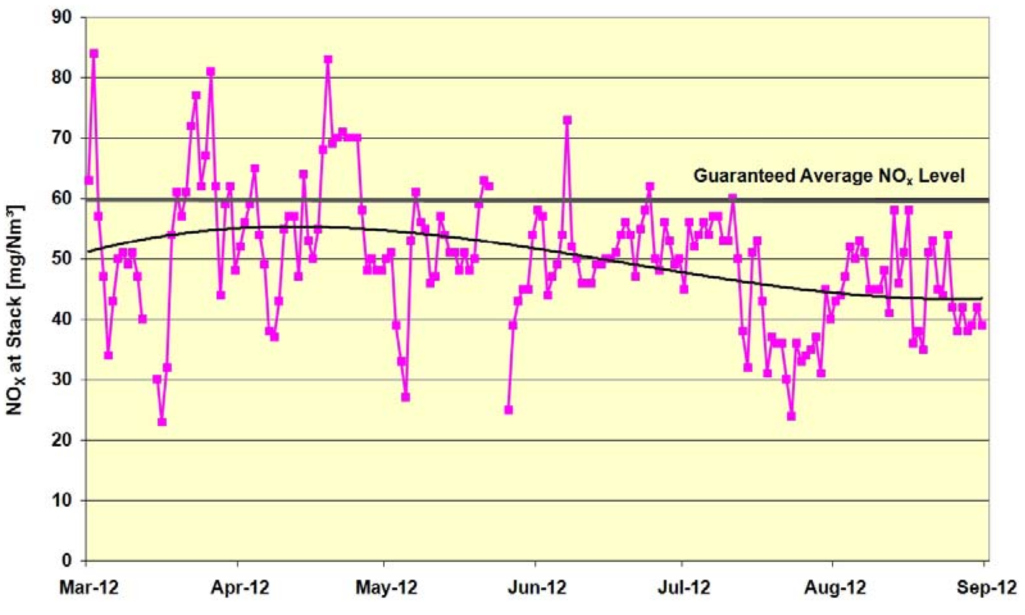


Figure 9: Daily NO_X Averages Line 11 – March to September 2012

It is difficult to measure NH_3 slip at the end of the boiler, since ammonia and chlorine form ammonia chloride which precipitates in the cold pipes of the measuring devices. Insulating and heating of the measuring lines would certainly improve measurement quality.

In order to minimize NH_3 slip, the reagent has so far 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_x. Since regular operations showed that the amount of ammonia removed from the flue gases was higher than expected, an increased slip can be tolerated in the future.

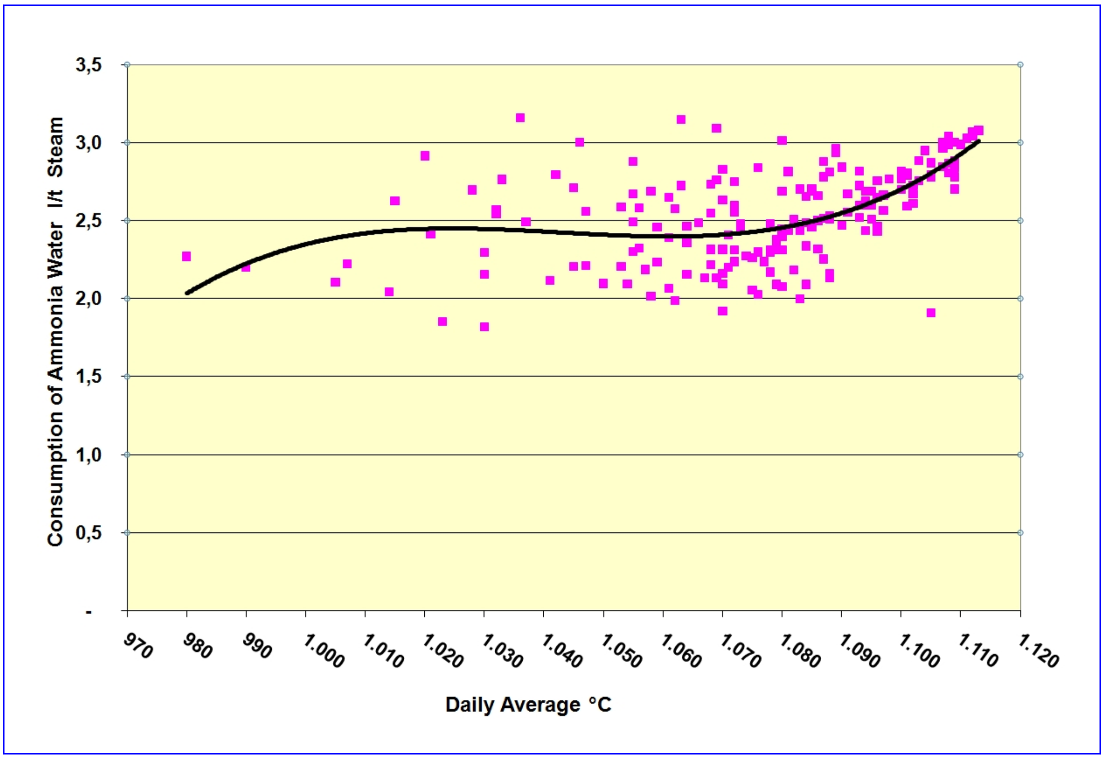


Figure 10: **Variations in Specific Ammonia Water Consumption**

There are plans to optimize efficiency of the SNCR plant and to inject more reagent between point “A” and point “B”. Expectations are that this will considerably reduce the consumption of ammonia water.

The daily NO_x averages in **Figure 9** clearly demonstrate that the required emission levels are always met. During the first nine months an annual NO_x average of 50 mg/Nm³ (dry at 11 % O_2) was obtained. This compares to the SCR plant which reached an annual NO_x value of 45 mg/Nm³. The daily NO_x average still varies frequently, but mostly it lies below the approved emission level of 65 mg/Nm³.

The specific ammonia water consumption (**Figure 10**, liter per ton of steam) shows significant fluctuations caused by rising flue gas temperatures in the boiler. When the boiler was commissioned after revision in March 2012 it was completely clean. After a few weeks / months of operation the heat exchangers get fouled and the heat from the flue gas cannot be absorbed as efficiently as before. It can be seen clearly how the ammonia water consumption increases, depending on the rising average flue gas temperature measured in the agam level **(Figure 11).** The highest temperature is measured in section 4 (refer to **Figure 5**). Here, a relatively high proportion of NH_3 is burnt to NO_x since temperatures in section 4 lie approx. 75 °C above the average temperature of the boiler’s cross-section.

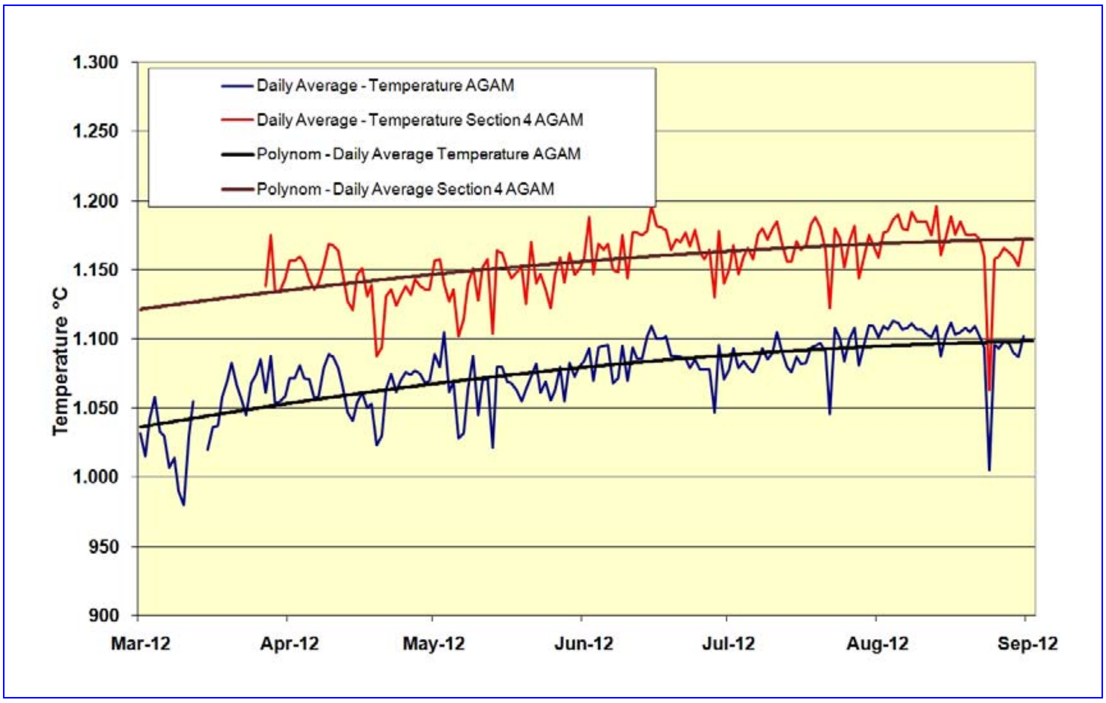


Figure 11: **Increase of Average Temperatures During a Service Interval**

5.1. Contamination of By-Products Resulting from Flue Gas Cleaning

During the design phase it was expected that NH_3 slip from the SNCR plant would be absorbed in the acid scrubber, reach the spray-dryer together with the waste water and return into the circuit. In order to prevent the accumulation of NH_3 slip, the installation of an NH_3-stripper was considered necessary for separating ammonia from the waste water of flue gas cleaning system. However, the stripper has not been installed yet, since operating experience shows that the NH_3-concentration is within acceptable limits at all three lines.

According to the operating experiences, ammonium chlorides formed by flue gas reduction are deposited to a larger extent than expected in the spray dryer along with the by-products. Therefore, an ammonia stripper is not needed any more, even if all three SNCR plants operate simultaneously. The contamination of the by-products of flue gas purification with ammonium salts is acceptable with regard to disposal.

6. Availability

The availability of the overall plant is hardly affected. 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 for new ones in time. The lances should be replaced one after the other in order not to affect the half-hourly averages of 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 down-times 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 so 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.

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

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.

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

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

Table 2 indicates that operating costs for reducing 1 ton of NO_x 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 costs for SCR are at least 5 times higher than for SNCR which clearly shows that an SNCR plant with its better cost-benefit ratio is more economical and therefore much more effective protecting the environment.

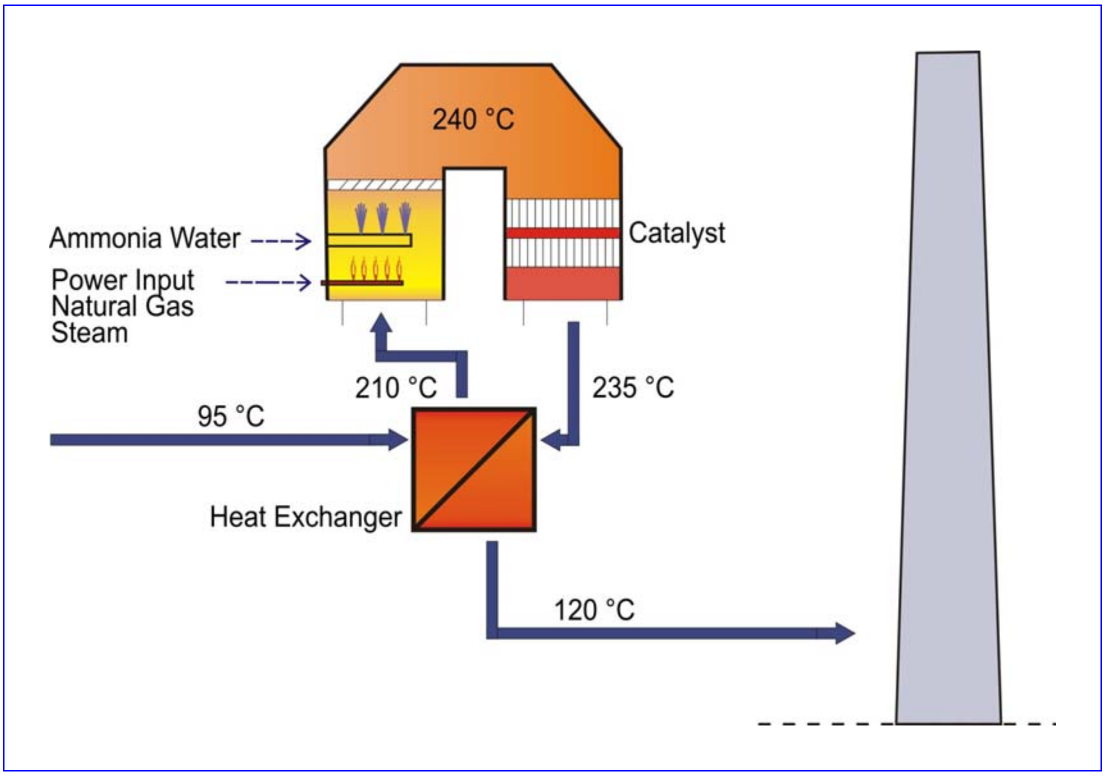


Figure 12: **Flow-Chart SCR Plant after Flue Gas Reduction**

Operating Data	Unit	SCR NH$_4$OH (24.5 %)	SNCR NH$_4$OH (24.5 %)
Throughput of waste	t/h	25	25
Flue gas volume flow	Nm^3/h, tr	100,000	100,000
Operating hours	h/a	8,000	8,000
NO$_X$ raw gas concentration	mg/Nm^3	330	330
NO$_X$ clean gas concentration	mg/Nm^3	45	50
NO$_X$ reduction per line	kg/h	28.5	28
NO$_X$ reduction (three lines)	t/a	684	672
Ammonia water 24.5 % (three lines)	t/a	800	4,000
CO$_2$ (three lines)	t/a	12,000	
Consumption of compressed air incl. agam	Nm^3/h		500
Consumption of deionized water	m^3/h		1.2
Additional consumption by suction draught	MWh/a	6,100	
Consumption of natural gas	Nm^3/a	6,600,000	

Tab. 2: **Operating Data - SCR versus SNCR (per Line)**

8. Summary and Outlook

The results of more than one year of operation show that SNCR technology can reach comparably low NO_x emission levels as with SCR. These achievements could be realized essentially by combining SNCR with the acoustic temperature measurement system (agam) 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 m³ per year – nor the power for re-circulating the flue gases is needed any more. This reduces the emissions of CO_2 considerably as well. Consequently, SNCR technology compares positively to SCR and is certainly the better technical solution for the environment (**Table 3**). 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.

SCR	SNCR
Comparable NO_x clean gas values (45 mg/Nm³)	Comparable NO_x clean gas values (50 mg/Nm³)
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
Investment costs – approximately 5 to 10 times higher than for SNCR	Low investment costs
High operating costs	Low operating costs
High maintenance costs	Minimum maintenance requirements

Tab. 3: Comparison - SCR versus SNCR

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_x 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/Nm³ NO_x in clean gas and NH_3 slip < 10 mg/Nm³. 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_x reduction.

9. Literature

Chvalina J., Seitz A., von der Heide, B.: „Langjährige Erfahrungen mit nichtkatalytischer Entstickung in kohlegefeuerten Kesseln in der Tschechischen Republik“, VGB-Tagung, Düsseldorf, 17. April 1997

von der Heide, B.: „Ist das SNCR-Verfahren noch Stand der Technik“ in:
Thomé-Kosmiensky, Michael Beckmann (Hrsg.): Energie aus Abfall – Band 4. Neuruppin: TK Verlag Karl Thomé-Kosmiensky, 2008, S. 275 – 293

von der Heide, Bernd: - SNCR Process – Best Available Technology for NO_x Reduction in Waste to Energy Plants, Power-Gen Europe, Milan, June 3 – 5, 2008

von der Heide, B. Langer, P.: Effizienz und Wartungsfreundlichkeit des SNCR-Verfahrens
Thomé-Kosmiensky, Michael Beckmann (Hrsg.): Energie aus Abfall – Band 7. Neuruppin: TK Verlag Karl Thomé-Kosmiensky, 2010, S. 729 – 753

von der Heide, B.: Advanced SNCR Technology for Coal Fired Boilers – 200 MW in Germany and 225 MW in Poland, Power-Gen Europe, 8.-10. Juni 2010 in Amsterdam, NL

von der Heide, B.: Advanced SNCR Technology for Power Plants, Power-Gen International, 13.-15. Dezember 2011 in Las Vegas, USA

Thomé-Kosmiensky, Michael Beckmann (Hrsg.): Energie aus Abfall – Band 10. Neuruppin: TK Verlag Karl Thomé-Kosmiensky, 2013, S. 683 – 702

Various documents of the company Bonnenberg + Drescher GmbH, Aldenhoven