

- SNCR Process -
Best Available Technology for
NO_x Reduction in Waste to Energy Plants



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Best Available Technology for NOx Reduction in Waste to Energy Plants

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1. Introduction

For about 20 years SNCR systems have been used in waste incineration plants, and rather occupied a niche position in the nineties. This was mainly due to lacking experience with this fairly new process, which made approval processes rather difficult and delayed them in an incalculable manner. Usually, operators were more interested in getting a speedy approval than in cost effectiveness, and therefore they mostly chose systems where least resistance was expected in the approval process.

Rethinking started with the slow-down of the economy at the end of the nineties. Allocating costs for waste incineration plants to waste charges became more difficult. Biomass plants, which are also operated under the same regulations are subjected to a much higher cost pressure. Because of that, solutions are preferred now that fulfil all technical requirements of the regulations and are more cost-effective, instead of searching for the maximum technical solutions for these systems. In biomass incineration plants the SCR technology practically does not play any major role. But also most of the waste incineration plants have been equipped with SNCR systems since about 2000.

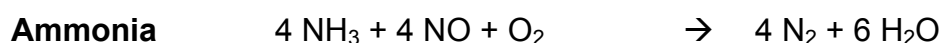
Discussions about a reduction of the emission limits for waste incineration plants have also challenged the NOx limits. Now, the draft of the 37th BImSchV in Germany aims at NOx limits of <100 mg/Nm³ compared to the currently valid 200 mg/Nm³. In this connection, it is a widely spread opinion that clean gas values of < 100 mg/Nm³ with an acceptable NH₃ slip can only be obtained in a SCR process, which would mean the end to the SNCR technology for waste incineration plants if this opinion prevails.

2. Technical Principles of the SNCR Process

In a **Selective Non-Catalytic Reduction** (SNCR) process of nitrogen oxides, reductants in an aqueous solution (ammonia water, urea) or in gaseous form (ammonia) are injected into hot flue gases. Following the overall post-combustion reactions for



or for



molecular nitrogen, water and carbon dioxide are formed. The optimum temperature range, where a noticeable NOx reduction is achieved, is between 900 and 1,100 °C

depending on the composition of the flue gas. Above this temperature range ammonia is oxidised to an increasing extent, i. e. nitrogen oxides are formed. **(Figure 1)**

At lower temperatures the reaction rate is slowed down, causing an ammonia slip which may result in the formation of ammonia salts and may lead to secondary problems, downstream the flue gas path. Therefore, the ammonia slip should be kept at a minimum.

These chemical reactions are similar if catalysts are used and also take place in a limited temperature window, which however is in a range outside the furnace or the boiler.

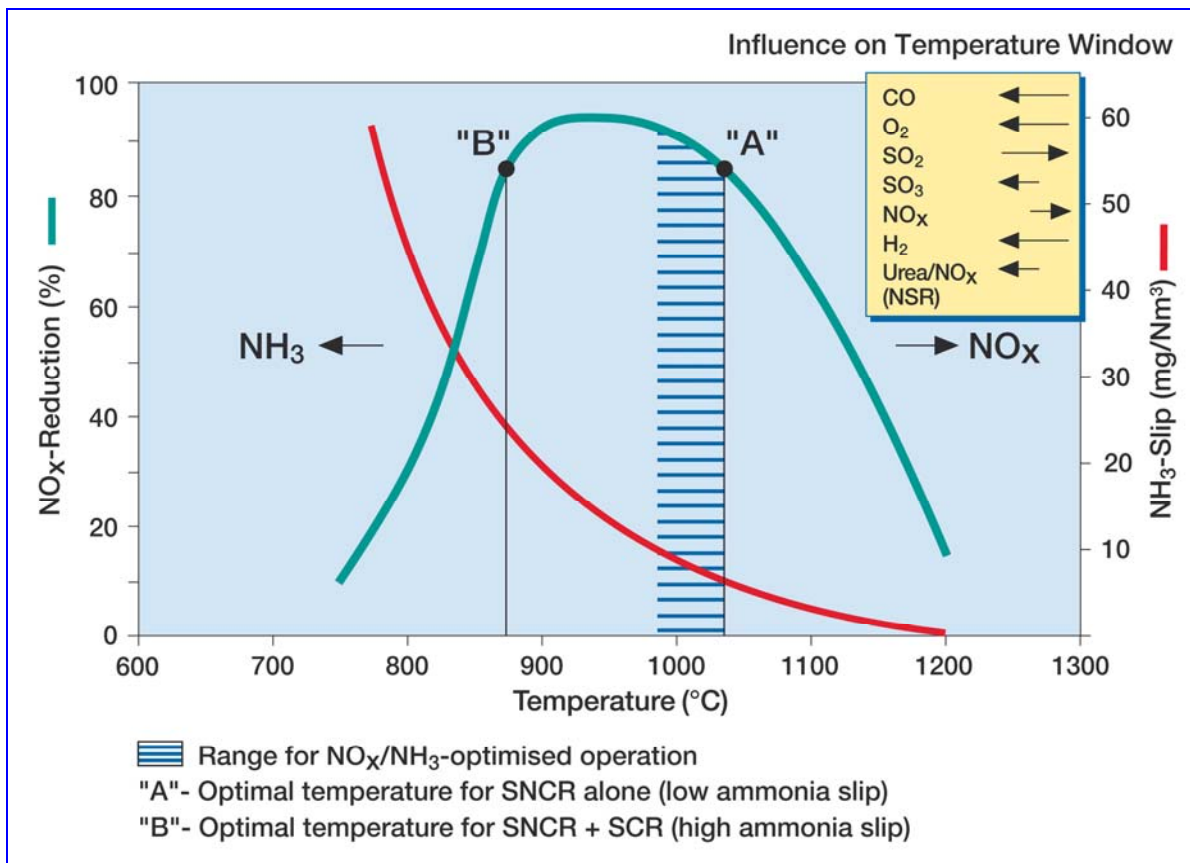


Figure 1: NO_x Reduction as a Function of Temperature

The objective of all NO_x control technologies is to reach a high NO_x reduction with a minimum consumption of reagent while the ammonia slip must be kept low at the same time. This only can be achieved with an even distribution of the reagents in the flue gas at the right temperature.

The urea based SNCR process of M&S consists of the following four steps

1. Distribution and mixing of the liquid droplets in the flue gas stream
2. Evaporation of the water in which the reagent chemicals are diluted
3. Decomposition of the reagent into reactive species
4. Gas-phase reaction between NH₂ and NO_x

Besides the distribution and mixing in the flue gas, the size of the droplets is very important for the results of the process. Droplets, which are too small, would evaporate too fast and possibly lead to a reaction at a too high temperature so that more NO_x would be formed.

Droplets which are too large, would evaporate too slowly so that the reaction would take place at the lower side or outside the temperature window, which would lead to an increasing of the ammonia slip, and decreasing of the NO_x reduction.

The major difference between both reductants, i.e. ammonia water and urea, is shown in a strongly simplified diagram in **Figure 2**. Urea dissolved in water only can be decomposed into reactive NH₂-species after the water enclosing the urea particles has been completely evaporated. The place in the flue gas where the reaction is to take place can be defined in advance by means of the water droplet size and the resulting penetration depth. If the water droplet is big enough, injection is possible into a place that is too hot for a NO_x reduction, because the reaction can take place downstream the injection point in a colder place within the flue gas. The mass of the dilution water, which is additionally used as a carrier medium for urea solution, ensures a high penetration depth at rather low energy consumption, and may cool down the flue gas to the desired temperature, if necessary.

In contrast, in plants using ammonia water the ammonia evaporates immediately when the ammonia water is being heated up respectively having entered the furnace. To ensure an optimum penetration depth more energy is required because of the lower mass of ammonia in gaseous form compared to a water droplet. In older plants this is accomplished by increasing the steam or air volume used as a driving medium.

However, a homogeneous distribution is very difficult to obtain as flue gases are very viscous and in general it is difficult to mix different gases. This disadvantage, which has often caused a higher ammonia slip in plants with ammonia water, can be compensated for to a major extent if dilution water is used as a carrier medium also for ammonia.

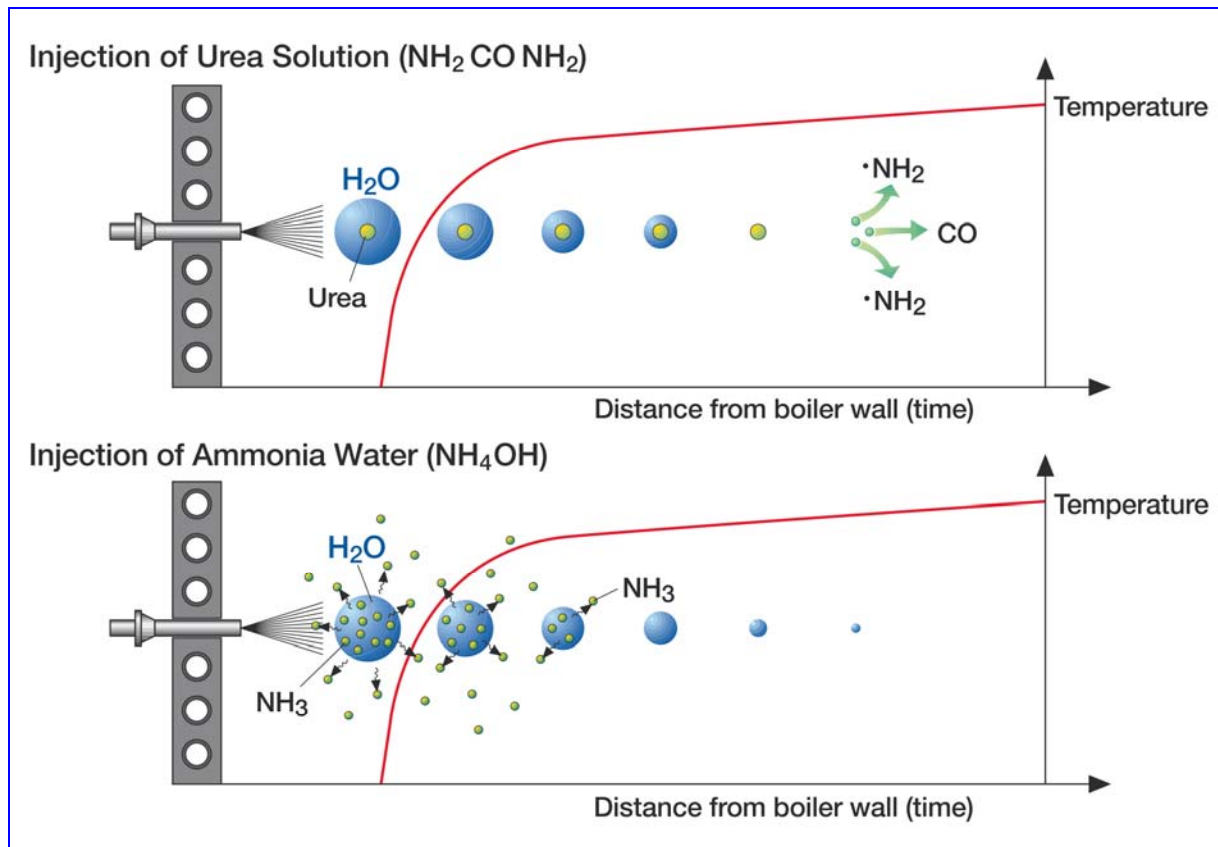


Figure 2: NO_x Reduction with Urea versus Ammonia Water

With the higher mass flow of the water a higher negative pressure is achieved in the jet stream after the nozzle compared to compressed air or steam alone (**Figure 3**). Due to the negative pressure the flue gas is sucked into the jet stream together with the ammonia and mixed. With this concept comparatively good results are obtained today with regard to NO_x reduction and ammonia slip, which have been the standard for urea solution already since the nineties.

Ammonia is a toxic and easily inflammable gas, readily soluble in water at ambient temperature. Operators consider ammonia water with a concentration just under 25% to be the optimum fluid for approval reasons. However, if the temperature increases, ammonia rapidly evaporates from water.

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

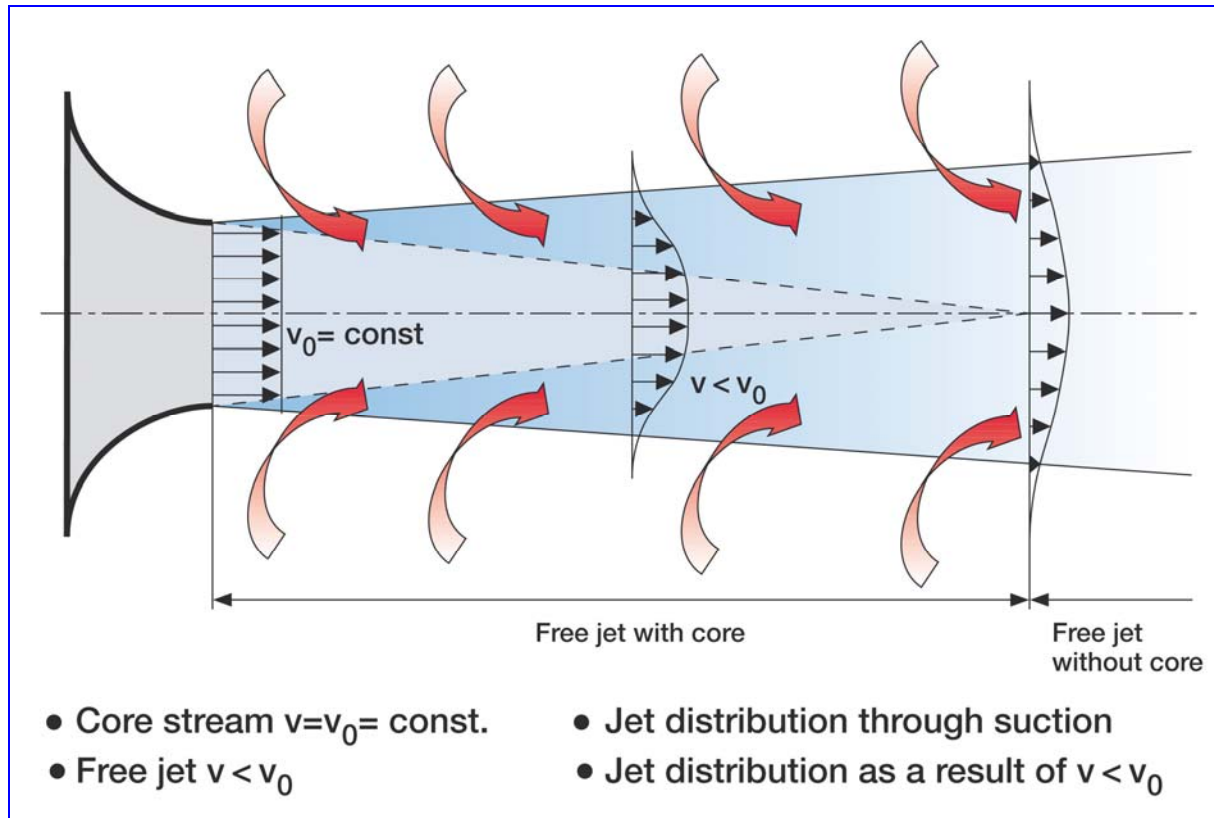


Figure 3: Mixing Flue Gas with Free Jet

Due to the chemical bonding of ammonia in the urea molecule, urea solutions may be heated up to 106 °C without ammonia gas evaporating. In contrast, the decomposition of urea into ammonia and carbon dioxide gas does not start below 130 °C and reaches its maximum at about 380 °C. Such high temperatures are not reached when the chemicals are stored, and therefore safety precautions as required for ammonia water are not necessary here.

The urea solution storage tanks are filled by means of compressed air generally generated by on-board compressors of the delivery vehicles. This method is not permitted for ammonia water, as the displaced gas volume from the storage tanks needs to be conveyed into the tank of the delivery vehicle via the gas exchange pipeline. Moreover, the less costly submersible pumps are not permitted for conveying the ammonia water from the tank to the injection lances as they involve an explosion risk. Under the German Federal Water Act (WHG) urea solution is allocated to the German water hazard class 1. This means only to prevent urea from getting into the ground water.

In contrast, ammonia water belongs to the water hazard class 2, and is subject to the German regulations TRD 451 + 452 for steam boilers or equivalent due to their high environmental hazard potential.



Pic1: Storage Tank for Ammonia Water with Pumping Station



Pic 2: Mixing and Metering Modul



Pic 4: Mixing Station and Storage Tank for Urea Solution



Pic 5: Storage Tank for Urea Solution

3. Concept for Plants designed for $\text{NO}_x < 200 \text{ mg/Nm}^3$

The simplified process flow scheme (**Figure 4**) shows the function and the scope of equipment of a typical SNCR system for urea solution as a reductant as operated in incineration plants according to the current regulations with NO_x reduction rates of up to 60%. Subject to the specific requirements these plants are generally equipped with one or two injection levels, which can be operated alternatively depending on the boiler load and/or the flue gas temperature.

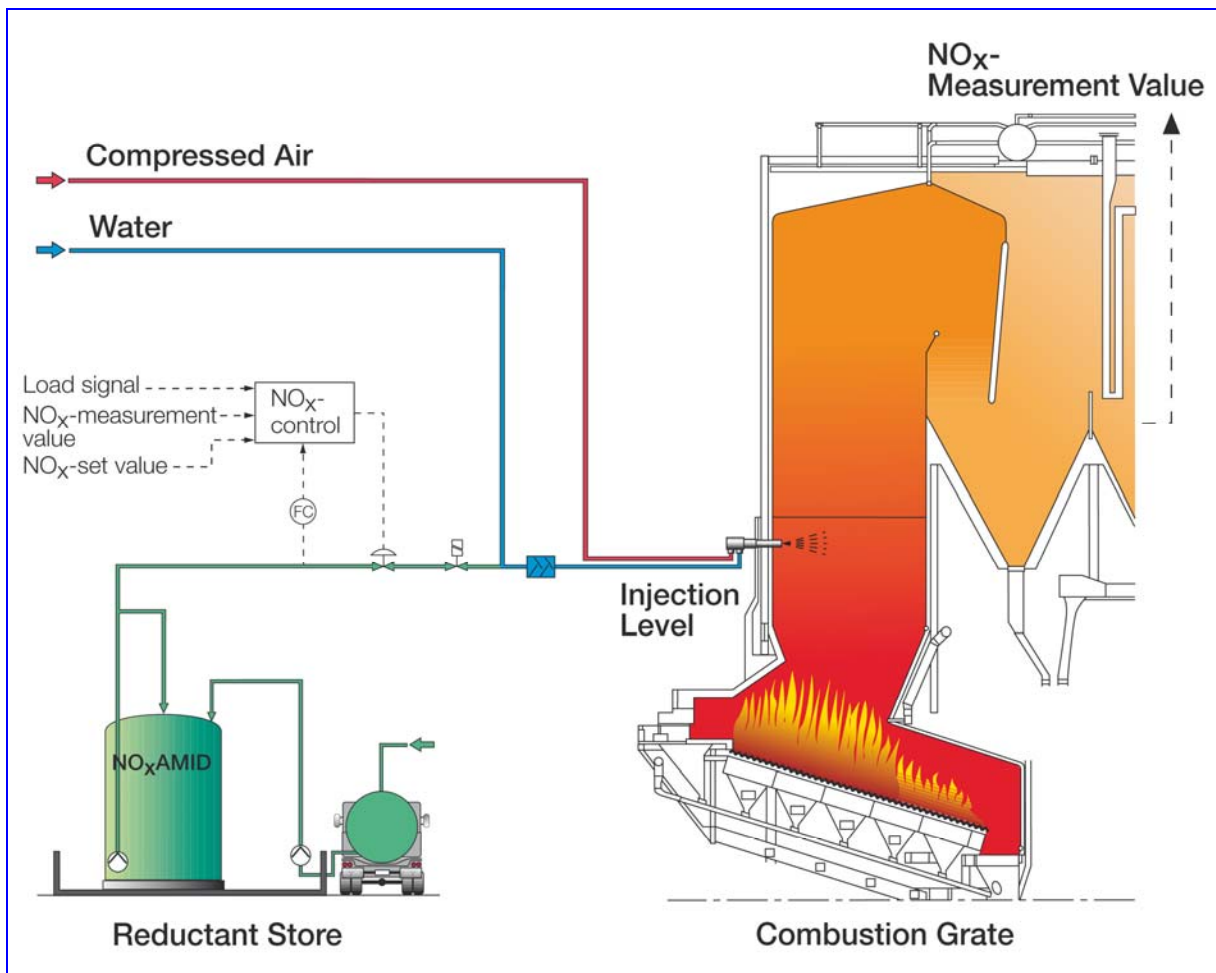


Figure 4: Process Flow Scheme with Urea Solution

With this concept NO_x values of 120 to 150 mg/Nm³ and a NH₃ slip of 10 to 15 mg/Nm³ can be maintained if the injection lances are arranged in such a way that a fairly wide temperature window for the injection can be covered. Temperature variations and imbalances, which cause insufficient reduction in one area, are compensated for by higher reduction rates in another area. To follow larger variations and imbalances in temperatures during operation, two injection levels have proven to be successful, which can be operated alternatively depending on the mean temperature measured at the end of the furnace. Under favourable operating conditions as can be found when incinerating homogeneous fuels and when the boiler load is constant, even NO_x clean gas values below 100 mg/Nm³ can be obtained with this configuration while the NH₃ slip still remains moderate.

4. Advanced Technology for Future NO_x-Limits

However, the engineering concept described above is not sufficient for higher and highest requirements as are being discussed for further limiting emissions of waste incineration plants, alternative fuel power stations and for co-incineration processes at cement works and in power stations. It must be ensured that under all prevailing operating conditions the reductant is injected across the overall cross section from each lance into the ideal NO_x/NH₃-optimised temperature window, which is only about 50 K wide and is highlighted in **Figure 1**. With the traditional concept this cannot be reliably achieved during all operation conditions of an incineration plant.

The constantly varying composition of the fuel in waste incineration plants results, for instance, in rapid and major changes of the heating value and the ignition behaviour of the fuel, causing considerable variations in the heat release and as a consequence the furnace temperatures (**Figure 5**). Moreover, the temperature window moves further upwards due to the increasing degree of deposits on the heating surfaces in the combustion chamber during operation.

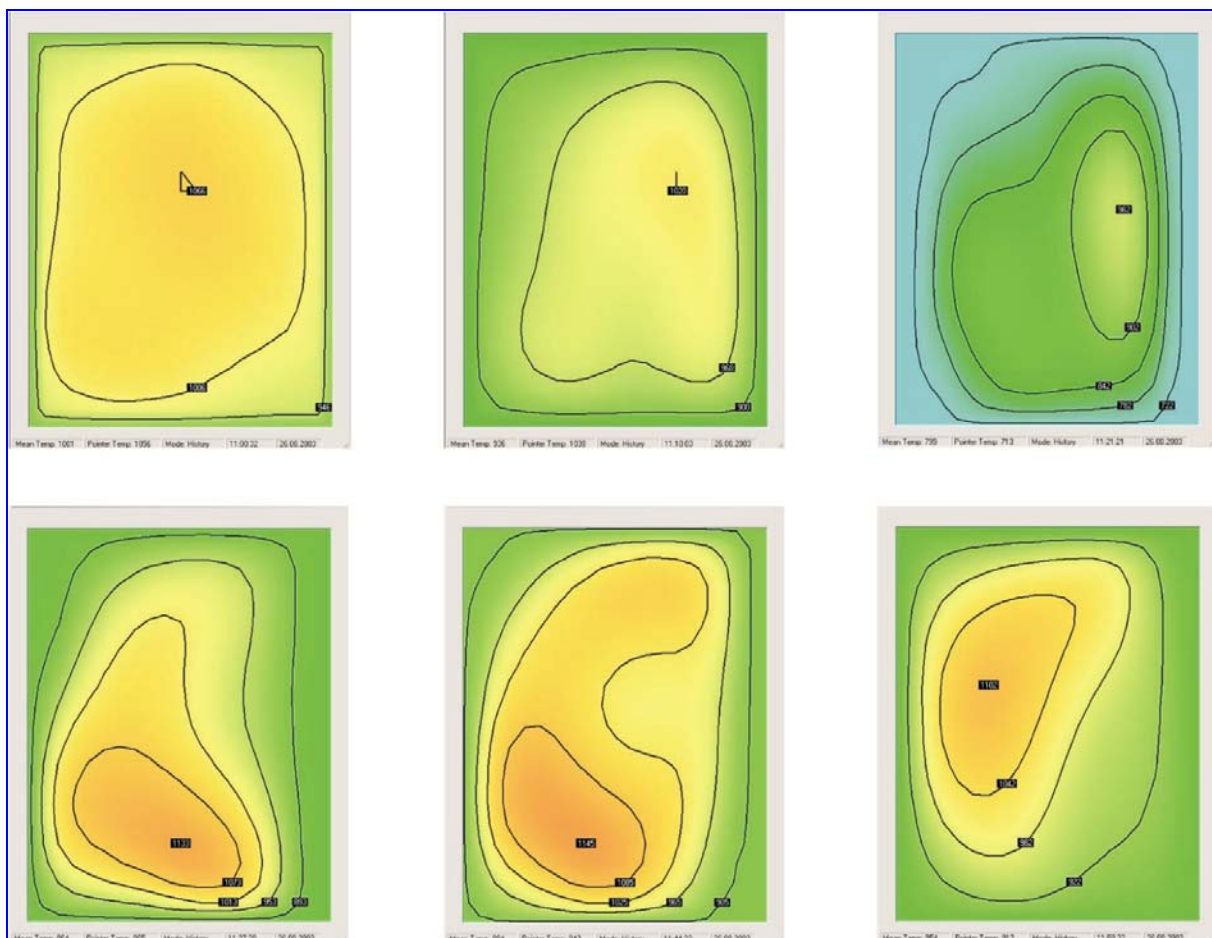


Figure 5: Changes of Temperatures in the AGAM Measurement Level of a Waste Incineration Plant within one hour during Operation

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Depending on the fuel type, fuel distribution and air supply, temperature imbalances of up to 150 °C - and sometimes even higher - are typical. The common furnace exit temperatures measured by means of thermocouples and averaged can be used as reference temperatures to a limited extent only as these average temperatures do not say anything about the temperature profile or the imbalances within the injection levels.

Moreover, also radiations from the furnace walls are affecting the measurements, resulting in deviations from real flue gas temperatures of 60 to 100 K. In addition, deposits on thermocouples lead to an increasing insulating effect in the course of the operation time. Depending on the thickness of such deposits, the measured temperatures are often only available in the process control system with a time-delay in the range of 10 minutes or even longer.

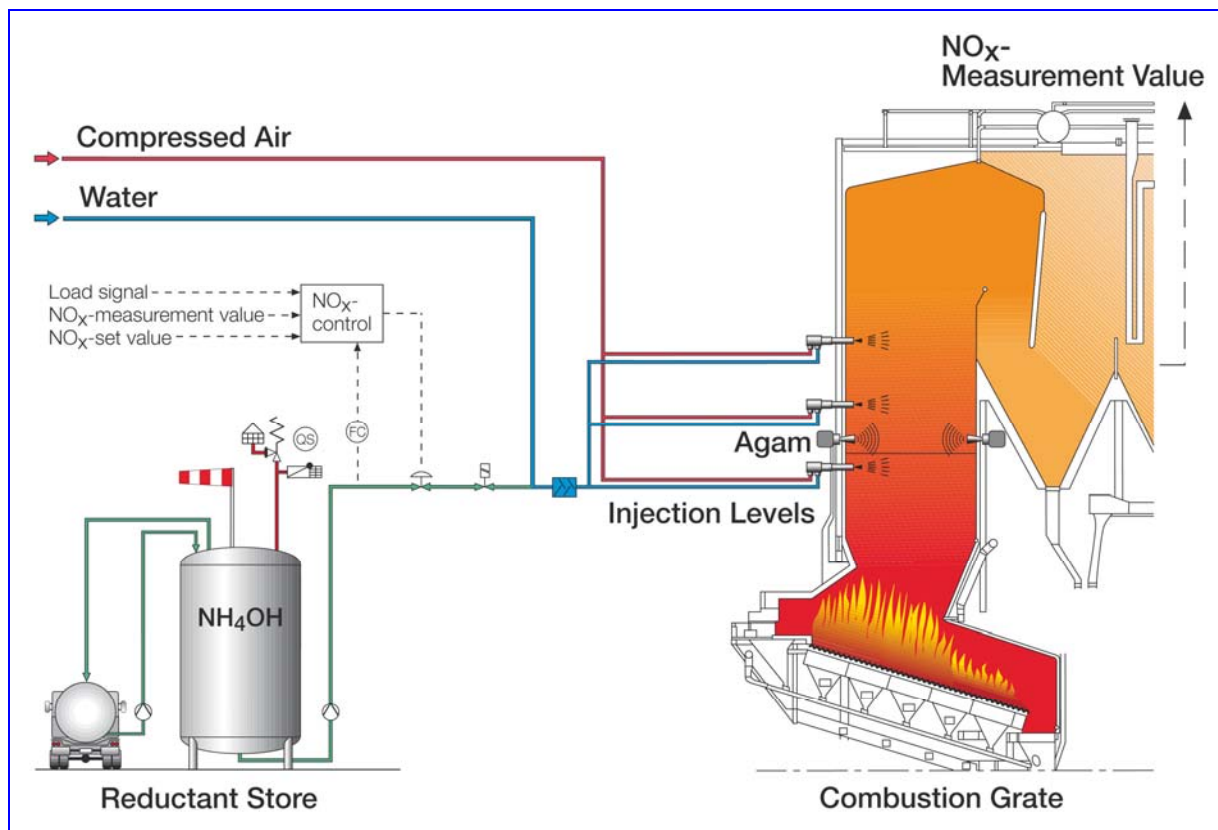


Figure 6: Process Flow Scheme NO_x/NH₃-optimised Operation with Ammonia Water

5. SNCR Optimisation with Acoustic Gas Temperature Measurement System (agam)

To ensure that in all possible operating scenarios the reductant is always injected into the upper range of the temperature window where the degree of NO_x reduction is highest and the NH₃ slip is lowest, acoustic gas temperature measurement systems (agam) are used in plants where highest performance is required. Agam is measuring the real gas temperatures in the combustion chamber cross-section near the injection points and determining temperature profiles.



Pic 6: SNCR Injection Lances with Acoustic Temperature Measurement (agam)

The system consists of transmitter and receiver units (**Figure 7**) 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 is opened, generating acoustic signals. The signals are recorded simultaneously on the transmitter and on the receiver side. The digitalised 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 the two-dimensional temperature distribution on one level immediately and without delay.

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 8**). This ensures that the reductant gets to the locations, which are most effective for the reaction even at rapidly varying flue gas temperatures, and the SNCR plant always operates in the optimum range with regard to NO_x reduction, NH₃ slip and reductant consumption.

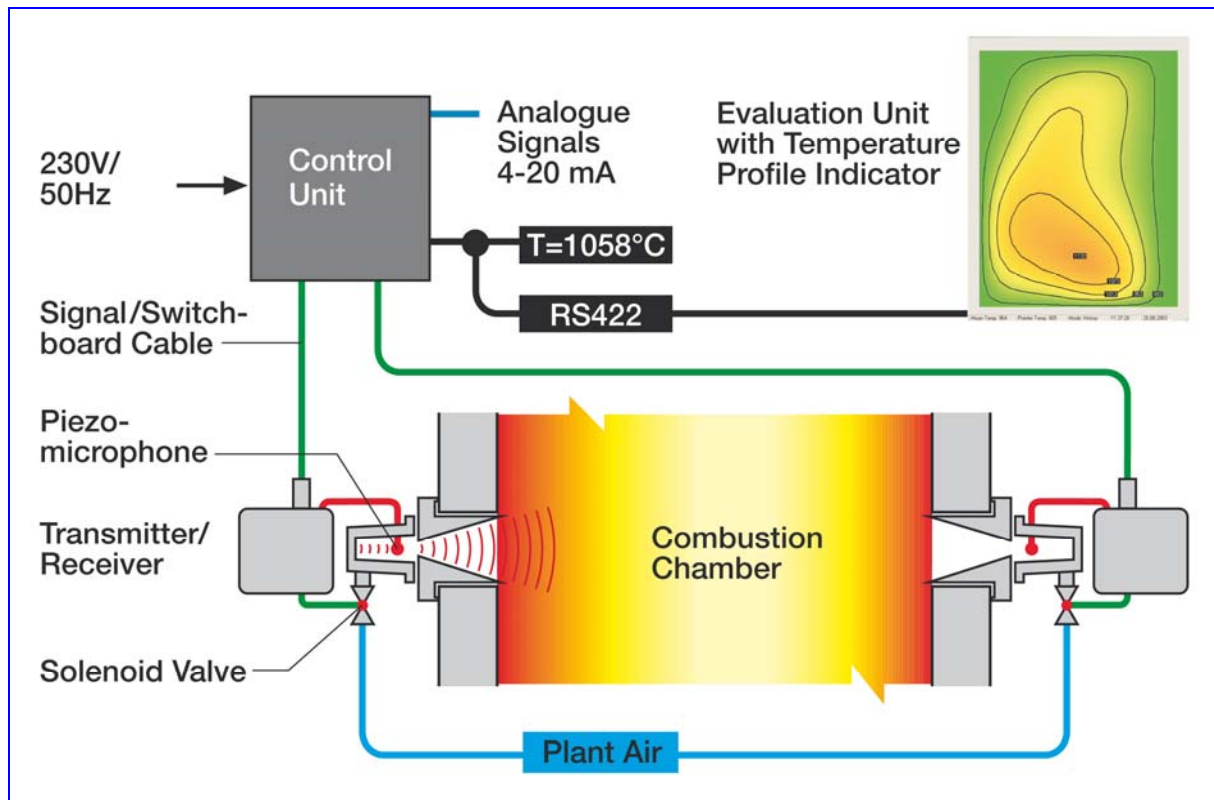


Figure 7: Basic Arrangement of the Acoustic Gas Temperatures Measurement System (agam)

Changing of lances depending on the flue gas temperature can only be a response to the changing and less optimal operating conditions in the furnace. However, it would be better to equalise the flow and the temperature profile of the flue gas during the combustion before the reductants are injected. This would relieve the SNCR control and since the changes of the lances would be less frequent the NO_x and clean gas concentrations would become more uniform. Also for the incineration process itself it would help to use the temperatures determined from the temperature measurement (agam) not only for directly incorporating them into the control system of the SNCR plant but also for controlling the firing performance and fire position on the grate. The additional costs would be rather moderate as the major components of the system are already provided in the SNCR plant.

The results obtained in several incineration plants during operation prove that NO_x clean gas values <100mg/Nm³ at a NH₃ slip <10 mg/Nm³ can be permanently achieved, and even values considerably below these figures are realistic. Reliable results are available, for instance, from a waste incineration plant in Germany, proving that NO_x clean gas values of 70 mg/Nm³ at a NH₃ slip of <8 mg/Nm³ have been maintained over a longer period of time.

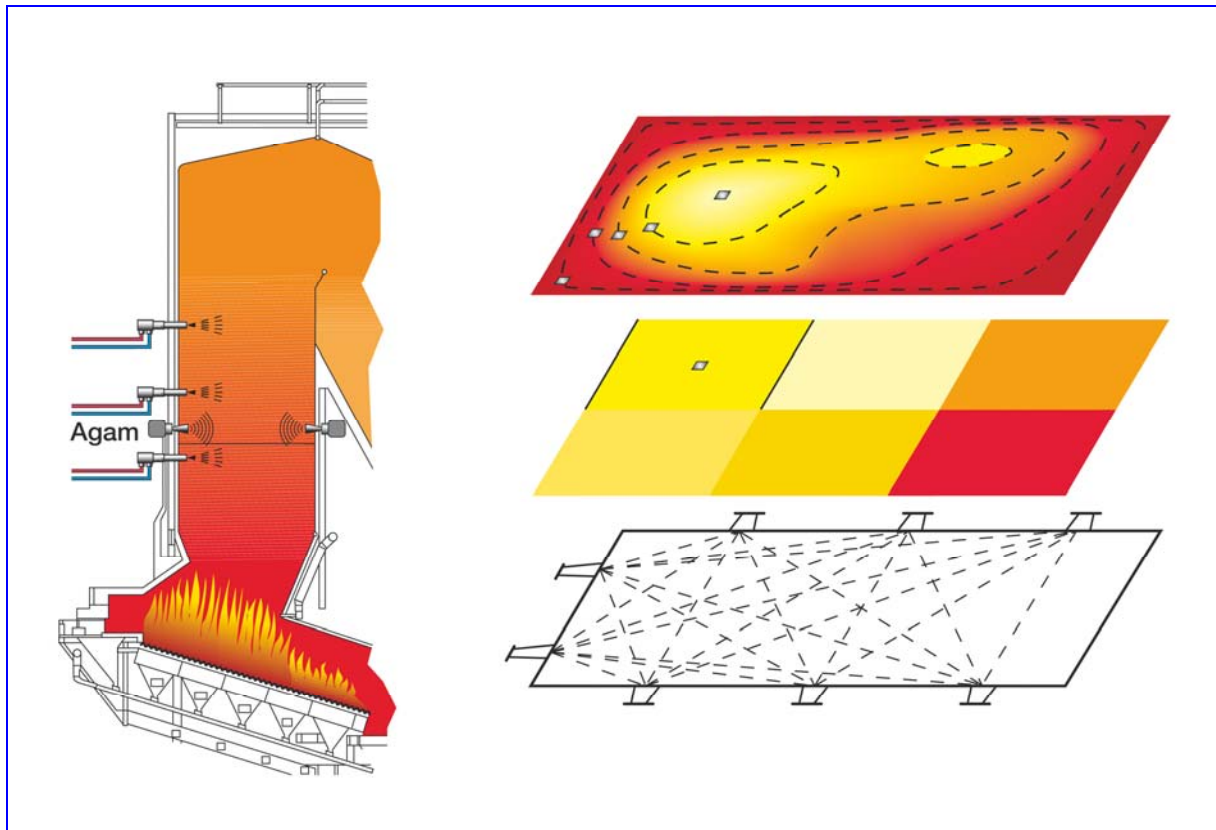


Figure 8: Temperature Measuring Points for the SNCR Process in the Furnace of a MSW

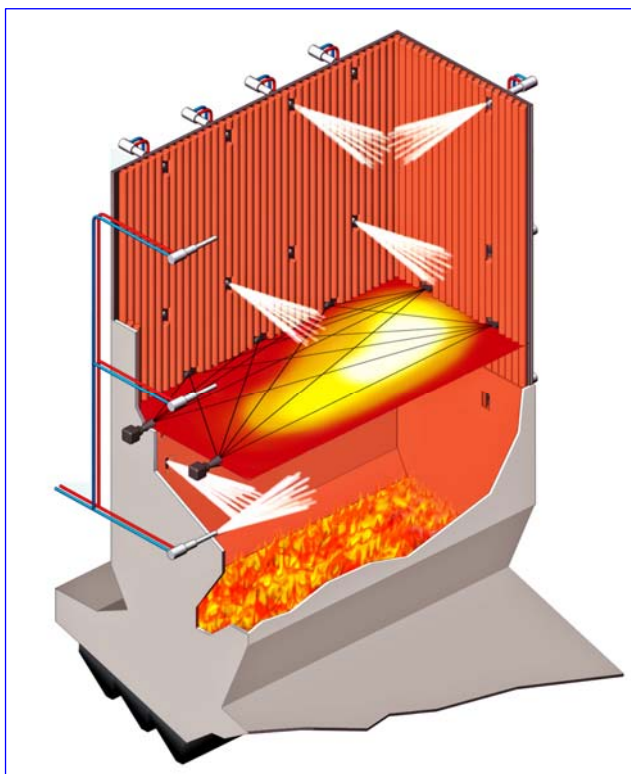


Figure 9: Changing of Individual Lances depending on Flue Gas Temperature

In Germany, Sweden and the Netherlands SNCR plants have been operated for several years, which have been designed for NO_x limits of <math><100 \text{ mg/Nm}^3</math> and reliably comply with the guaranteed values in continuous operation. The newer plants of them, which are equipped with an acoustic temperature measurement (agam) and three injection levels to switch each individual lance, are characterised by a specifically low NH₃ slip apart from their low NO_x clean gas values and high efficiency.

6. Comparison between SCR and SNCR

The average annual values published by operators of waste incineration plants, for instance in the internet, show that there is the tendency that plants equipped with SCR plants are continuously operated with NO_x clean gas values of <80 mg/Nm³.

The NO_x values published for waste incineration plants based on the SNCR technology are usually about 180 mg/Nm³ or sometimes even just under 150 mg/Nm³. This suggests that the limits of SNCR processes have been reached with these values.

But often the fact is disregarded that most of the SNCR systems have been designed for incinerations plants approved under the current regulations, i.e. for NO_x limit values <200 mg/Nm³. On the basis of the published data it is not possible to judge whether "only" the respective contractual requirements have been fulfilled or if better NO_x reduction rates can be achieved in the plants and what the potentials of the SNCR technology are.

The generally accessible emission values only confirm that the approved NO_x emissions can be reliably met with the SNCR process and, as the operating values are usually just below the limit values, it indicates, that the set values can obviously be controlled very well. NO_x values below the permitted limits would lead to higher operating costs due to higher reductant consumption, which would not be in the interest of the operators and are therefore avoided.

Undoubtedly, the SNCR technology has been further developed and improved over the approximately 20 years of its use. As early as at the beginning of the nineties a NO_x limit value of 100 mg/Nm³ had been discussed in Germany before the current limit value of 200 mg/Nm³ was established. Before the 17th BImSchV became effective comprehensive field tests had been carried out to prove that NO_x clean gas values of <100 mg/Nm³ and an acceptable NH₃ slip can be guaranteed in continuous operation with SNCR. The technical Know how and experience of today was not available at that time and could not be applied. Meanwhile injection systems and configurations have been developed to a level that an almost homogeneous distribution of the reductants across the entire cross-section in the combustion chamber is always possible. Based on the experience gained over the years in operating a number of different incineration plants also process relations and interdependencies are much better known now so that optimum conceptions can be used for any application.

The SCR process achieves NO_x clean gas values, which in waste incineration plants are 50 to 80 mg/Nm³ or about 20 to 50 mg/Nm³ below those of the SNCR process if plants have been designed for this reduction degree. However, this little advantage of the SCR technology of maximum 50 mg/Nm³ NO_x must be paid highly for by tolerating partially considerable economical, energetical and ecological disadvantages.

The investment costs of a SCR plant designed for the above NO_x clean gas values are about five times the costs of a comparable SNCR plant depending on their size, NO_x reduction and technical configuration.

In addition, the operating costs are higher due to the increased energy consumption of the blower for overcoming the pressure drop in the additional heat exchangers and the catalyst as well as for reheating the flue gases by means of steam, oil or natural gas.

The example of a fictitious waste incineration plant compares below three different flue gas denitrification systems with regard to investment and operating costs. These systems are a SCR plant, a standard SNCR plant designed for a NO_x clean gas value <200 mg/Nm³ using urea and a SNCR plant designed for an NO_x clean gas value <100 mg/Nm³ using ammonia water as the reductant.

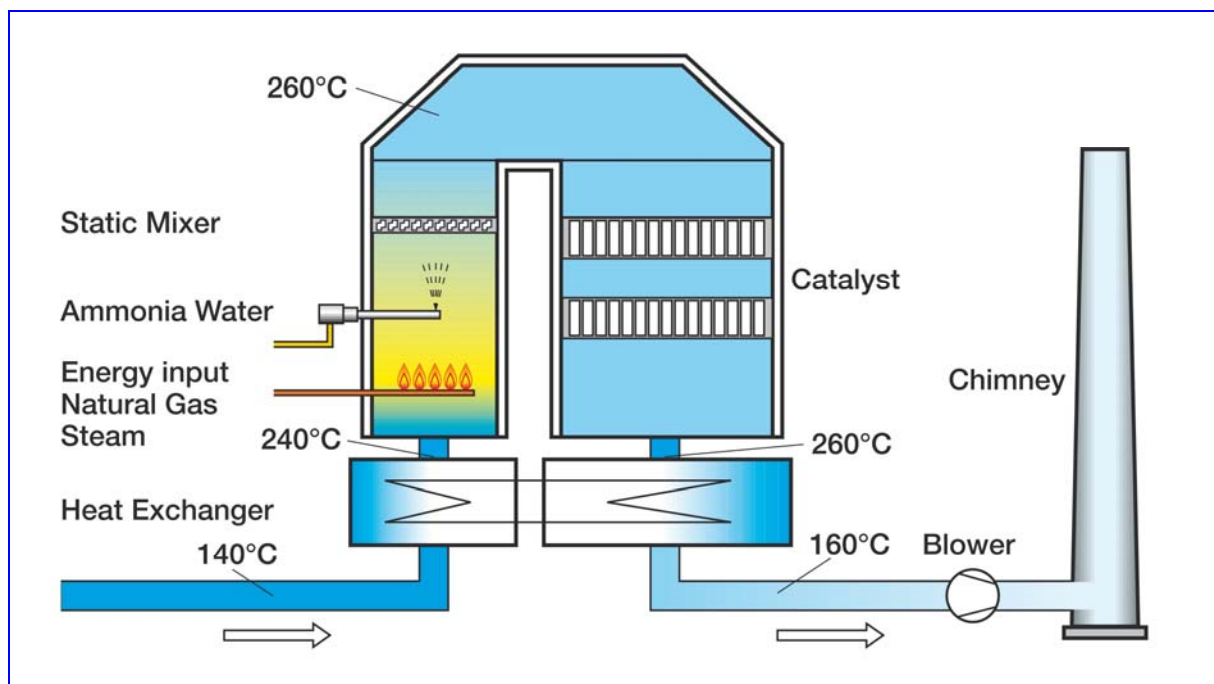


Figure 10: Process Flow Scheme of a SCR Plant downstream of a dry Flue Gas Cleaning System

The SCR unit is installed downstream of a dry flue gas cleaning system. A simplified process flow scheme is outlined in **Figure 10**. The pressure loss across the heat exchangers, the mixer, the flue gas ducts and the catalyst elements is assumed to amount to a total of 25 mbar. The temperature loss of the flue gas is assumed to be 20 – 25 K. The energy required for compensating the temperature loss is supplied via natural gas burners.

The investment costs of the SCR system amounting to EUR 2,500,000 are about EUR 2,000,000 higher than those of the SNCR system designed for a NO_x clean gas concentration <100 mg/Nm³. The investment costs of the urea-operated SNCR plant for NO_x clean gas values of 200 mg/Nm³ according to the current regulations in the EU are estimated to amount to about EUR 200,000, thus leading to a considerable lower annuity of both SNCR systems in the example compared to the SCR plant.

Due to the lower efficiency, the operating costs for reductants are higher in both SNCR systems compared to the SCR system. On the other hand, considerable higher costs would arise in the SCR system for additional electrical energy to operate the blower to overcome the pressure loss as well as for external energy (natural gas) for reheating the flue gases so that the overall operating costs for each of the two SNCR systems are much lower. Not considering the annuity and the additional costs for regenerating and replacing the catalysts the annual savings per system amount to a total of about EUR 240,000 to 300,000 depending on the chosen concept of the SNCR system. This is also in the range of the amount of savings GMVA Oberhausen has published when taking into account that the waste throughput of this plant is about 25 MT/h compared to 15 MT/h of the model plant.

The flue gas denitrification system of the GMVA plant was changed from the SCR to the SNCR process in 2004 to increase the availability, which had been considerably affected by corrosion damages in the plate heat exchangers, and to react on increasing energy costs. GMVA publications show that savings of the operating costs alone are realised amounting to about 2,100,000 EUR/a for the four systems. This means 525,000 EUR/a for one incineration plant alone.

In the literature SNCR processes are frequently criticised for their excessive NH₃ slip, which is causing the formation of ammonium salts together with the SO₃ and HCl content in the flue gas, which in turn may have a serious impact on the function and availability of downstream plant components. This may, in fact, be true for plants with high SO₃ and low particulates concentrations, such as heavy oil firing systems. However, such contemplations often do not consider that SCR processes partially involve much bigger problems with such fuels due to high SO₃ and vanadium pent

oxide contents. SO₃ reacts with the ammonia injected for the reduction of NO_x also in the catalyst and forms ammonium salts generating deposits with the fine dust. Moreover, vanadium pent oxide increases the reactivity of the catalyst, increasing the conversion rate of SO₂ into SO₃ and causing the formation of sulphuric acid and related corrosion problems.

	Unit	SNCR Urea (45%)	SNCR NH ₄ OH (25%)	SCR NH ₄ OH (25%)
Waste throughput	MT/h	15		
Flue gas volume stream	Nm ³ /h,dry	80,000		
Operating hours	h/a	7,800		
NO _x baseline	mg/Nm ³	400		
NO _x clean gas concentration	mg/Nm ³	200	100	70
Pressure loss	mbar			25
Temperature increase	°C			20
Investment costs	EUR	200.000	500.000	2.500.000
Operating time	years	15	15	15
Interest rate		6%	6%	6%
Annuity	EUR/a	20.000	50.000	250.000
Ammonia water	EUR/h	-	16,50	6,00
Urea solution	EUR/h	11,30	-	-
Process water	EUR/h	0,58	-	-
Demineralised water	EUR/h		1,20	
Electrical energy	EUR/h	0,15	0,15	6,70
Natural gas	EUR/h	-	-	38,00
Compressed air	EUR/h	2,00	2,00	-
Operating costs per hour	EUR/h	14,03	19,85	50,70
Operating costs per year	EUR/a	109.434	154.830	395.460

Table 1: Cost Comparison between SCR and SNCR

Contrary to the widespread opinion the formation of ammonium salts in waste incineration plants as a result of the NH₃ slip from SNCR systems does not cause problems in the plant components if the systems concept is right. In downstream wet scrubbers NH₃ is absorbed almost completely and may affect the disposal of the by-product from the flue gas treatment plant. GMVA speaks, for instance, only about additional disposal costs of EUR 122,000 per year for four plants, which is not very much compared to the discussed savings.

GMVA also report that SO₃ concentrations of only 5 mg/Nm³ have resulted in the formation of ammonium hydrogen sulphate and thus in clogging and damaging plate heat exchangers and finally affected the availability of the overall plant to an extent of about 600 h/a.

In contrast, the availability of the overall plant using the SNCR process is practically not impaired. All critical components for its operation, such as pumps, which may affect the availability of the plant, are provided redundantly. The injection lances in contact with the flue gas requiring regular maintenance as wearing parts, may be checked and replaced, if necessary, during operation without affecting it.

From an environmental point of view the additional NOx and CO₂ emissions from the additional energy input cannot be ignored either. Assuming that with the SCR technology clean gas concentrations are obtained, which are not more than 30 mg/Nm³ below those of the SNCR technology without any additional equipment, such as an additional catalyst layer, the NOx emission is only about 2.4 kg/h lower. On the other hand, the CO₂ emission in the SCR plant released into the environment - that results from the combustion of natural gas in the duct burners and from the electrical energy required for covering the higher energy consumption for the blower - is about 300 kg/h (2,400 kg/a) higher. Moreover, most of the reduction in NOx emissions is paid for by an additional increase in other places.

7. State of the Art or Best Available Technology (BAT)

Now, is the SNCR technology a state-of-the-art technology and/or the "best available technology" (BAT) or is it not?

According to the European Unions directive 96/61 EC "Best Available Technology" shall mean the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular technologies for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole:

Best: shall mean most effective in achieving a high general level of protection of the environment as a whole;

Available: techniques shall mean those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the

techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;

Technology: shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned.

As described in this paper, SNCR systems have demonstrated their efficiency and reliability in continuous operation with various fuels in several hundred combustion plants in Germany alone over many years and for sure belong to those plants that are most effective in achieving a high level of protection of the environment as a whole. Undoubtedly it is also an "available technology" having been designed and engineered to an extent that, under consideration of the cost and advantages, their application is possible under economically and technically viable conditions prevailing in the concerned industrial sector. This also applies to systems of the latest generation which, due to their acoustic temperature measurement system and costlier injection systems, involve investment costs that are about double as high as those of conventional SNCR systems.

Moreover, lower NO_x clean gas values in SCR systems lead to higher NO_x and CO₂ emissions in other locations so that the advantage regarding the high level of protection of the environment is not be given.

In particular when comparing both processes, SCR and SNCR, with regard to their costs and advantages in most of the incineration plants built and operated under the European regulations, there is no reason to support a technology where the investment and operating costs are much higher than those of a technology having been successful in many plants over many years.

Due to the relatively lower technical effort it is much easier to „*design, built, maintain, operate and decommission*“ SNCR systems. Apart from the investment and operating costs discussed above, also the costs of disposal of the catalysts play a major role in case of a closedown.

8. Summary and Outlook

Over several years of continuous operation the SNCR technology has proved to be a reliable process for the NOx reduction in incineration plants required to meet the limit values of the European directives. Moreover, there are reliable operating results from several plants proving that the potentials of this technology are not yet utilized by complying with NOx limit values $<100 \text{ mg/Nm}^3$. The number of SNCR systems which is more than ten times higher than the number of SCR systems built since 2000 impressively demonstrates that the current state of the art is determined by the SNCR technology. With good reason - as this paper proves.

Even if the SCR technology achieves higher degrees of NOx reduction, these systems, strictly speaking, do not comply with the state-of-the-art technology as in most cases their cost-benefit ratio is not reasonable and also the required level of protection of the environment in terms of the BAT must be doubted in many cases. In contrast and under due consideration of all relevant aspects the SNCR technology is the best available technology for the NOx reduction in incineration plants according to the German 17th BImSchV, as well as comparable regulations in Europe, and will play a major role in determining the state of the art also in the future.

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