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IS DE-NO_x BY SCR TO BE THE FUTURE IN US? – TECHNOLOGY AND TENDENCIES WITHIN APC-EQUIPMENT

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ABSTRACT

The paper will present available De-NO_x technologies as well as the paper will present the operational experience in European countries where the technology has been operating for approx. 10-15 years. The experience is based on Ramboll's experience with NO_x control on advanced WtE plants in Europe.

Technical SCR solutions will be discussed and specific technical obstacles and specific precautions to be taken will be highlighted and illustrated by showcases.

Investment and operating costs for SNCR versus SCR will be presented.

Finally it will be evaluated which effect De-NO_x at WtE facilities will have compared to the energy sector in general.

INTRODUCTION

The air emission limits have over the years been tightened both in Europe and in North America. Still more efforts are given by the European Union and the US EPA to implement stricter emission limits as well as WtE facilities are implementing more efficient technology in order to get a better public acceptance and to reduce the emission of pollutants.

NO_x emission has become a global problem and "hot-spots" have been identified in certain areas of US, Europe and Asia as illustrated in Figure 1.

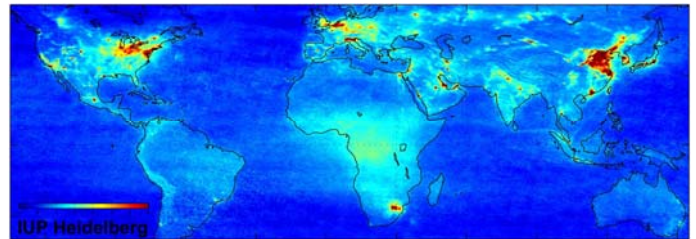


Figure 1. NO_x Hot Spot. Source. IUP Heidelberg, Institut für Umweltphysik

This has resulted in the fact that the NO_x emission limit for WtE facilities in US has been heavily tightened and recently new WtE facilities have to deal with emission limits less than 50% of the EPA emission limits.

The WtE facilities have to take into consideration the cost for investment and the cost for operating more and more efficient De-NO_x.

Until recently WtE facilities in USA have been equipped with the Selective-Non-Catalytic-Reduction (SNCR) technology to comply with the regulatory requirements - will it also be the way forward or will the regulatory requirements be so strict that Selective-Catalytic-Reduction (SCR) technology will be required for future plants?

EMISSION STANDARDS FOR WTE FACILITIES

Waste incineration produces flue gas that contains a spectrum of components (e.g. dust, acidic compounds, heavy metals, and dioxins). To avoid emission of these pollutants to the surroundings, extensive flue gas treatment (FGT) is necessary

before discharge to the air reducing the level below other energy producing facilities.

Table 1 below shows the typical raw gas concentration of pollutants in flue gas before the air pollution control equipment. The raw flue gas data are based on a WtE facility receiving mixed MSW (60-70%) and industrial waste similar to MSW (30-40%). To compare the raw flue gas data with the cleaned flue gas the emission limits in the European Union (EU) is shown. The EU limits (EU Directive 2000/76/EF on Waste Incineration) are more or less similar to the recent US EPA regulation (MACT).

	Component	Unit (11% O ₂)	Raw flue gas quality (typical values, daily average)	Raw flue gas quality (typical values, ½ hour average)	EU emissions requirements
Acidic compounds	TSP / Dust	mg/Nm ³	2000	5000	10
	SO ₂	mg/Nm ³	400	600	50
	NO _x ¹⁾	mg/Nm ³	400	600	200
	HCl	mg/Nm ³	600	2000	10
	HF	mg/Nm ³	10	50	1
Heavy metal	Hg	mg/Nm ³	0.5	1.5	0.5
	Cd	mg/Nm ³	1	5	N.D.
	Cd, Tl	mg/Nm ³	1	5	0.05
	Pb	mg/Nm ³	20	30	N.D.
	∑ As, Ni, Co Pb, Cr, Cu, V, Mn, Sb	mg/Nm ³	10	50	0.5
	Dioxins	ng TEQ/Nm ³	2	5	0.1

1) Some European countries has reduced the limit to 70/80 mg/Nm³

Table 1: Typical pollutant concentration in raw gas and emission limits (EU Directive 2000/76/EF on Waste Incineration)

The emission limit for NO_x at 200 mg/Nm³ has been in force for new European plants from the year 2000 and for existing plants from the end of 2005.

In some European countries a lower emission limit has been introduced. In Austria and Switzerland the NO_x limit is restricted at 80 mg/Nm³ and in the Netherland the NO_x limit is limited at 70 mg/Nm³.

In other European countries like Sweden a tax incentive has been introduced enforcing the WtE plants to operate with very low NO_x-emission at around 20-50 mg/Nm³.

A new European Industrial Air Act is under preparation and stricter air emission levels are being proposed and the NO_x emission limit is most likely to be tightened.

DE-NO_x METHODS

The air pollution control (APC) system consists of a number different treatment steps for the different types of air pollutants.

There is no universal method to select the best flue gas system for a given facility, since it depends on required guaranteed emission values, size of the plant, fee on pollutant emission, requirement of plume visibility from stack etc.

As the APC system in the US is dry or semi-dry I will concentrate only on these systems and do not in the following consider the precautions to take if the De-NO_x system is combined with wet flue gas treatment.

In dry and semidry APC-systems the flue gas is brought to react with lime in a reactor and the dust is collected in a bag house. filter. The process is illustrated in Figure 2.

The DeNO_x process could be a SNCR or a SCR process as illustrated in Figure 2. The SNCR process will always take place in the boiler part. The SCR can be located in various locations, in figure 2 the tail-end solution (the most common solution) is shown.

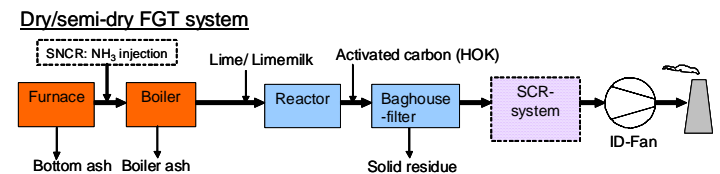


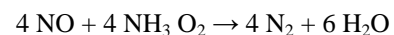
Figure 2. Illustration of dry/semi-dry FGT system and SNCR or SCR DeNO_x reduction

For waste incineration facility the general flue gas concentration is around 400 mg/Nm³ (daily average). However, modern WtE facilities with an advanced automatic combustion control (ACC) system, which all the major WtE manufacturers supply, are normally capable of reducing the NO_x level to 250 mg/Nm³ as well as recirculation of flue gas can result in lower NO_x emission. Still active NO_x removal is required to achieve NO_x levels below or under the emission limit.

The two most common methods are;

- Selective Non Catalytic Reduction (SNCR)
- Selective Catalytic Reduction (SCR)

In both cases ammonia (NH₃) or urea ((NH₂)₂CO) is added in a water suspension.



The stoichiometric consumption of ammonia is 1,5 kg 25% NH₃ per kg NO_x (as NO₂) reduced.

Based on theoretical calculations and operating experience surplus ammonia has to be added to the process to ensure

sufficient efficient reaction. The major part of the surplus ammonia is oxidised to N_2 , NO or will be used to the reaction with the formed NO. However a smaller part will leave the system as a so-called ammonia-slip.

If urea is used a side reaction takes place producing laughing gas (N_2O).

SNCR

For the SNCR process ammonia is injection into the flue gas in the furnace at the location where the temperature is around 850-900°C. The temperature is important as the optimal reaction between ammonia and NO_x takes place in this temperature span.

Surplus ammonia has to be added to the process for ensuring an effective reduction of NO_x . As an example is it necessary to add approx. 2.5 times the stoichiometric amount of ammonia for reducing the amount of NO_x with 80%.

The process demands a careful control of the ammonia injection as well as the combustion process as the temperature is essential for the DeNO_x process as the input (the nozzle) is fixed. Often 3 nozzle layers are required to ensure a sufficient NO_x control.

The consumption is normally 3-4 kg 25% ammonia water per ton (metric) waste by reduction of NO_x from approx. 400 mg/Nm³ to approx. 180 mg/Nm³ (55% reduction).

Emission values around 150 – 180 mg NO_x /Nm³ is commonly used for the SNCR process. Lower values – to around 100 mg/Nm³ – are possible with the SNCR process but the consumption of ammonia is relative high and the risk for high ammonia slip will increase.

Some European countries restrict the emission ammonia slip, for instance in Austria and Switzerland where the emission of ammonia is restricted to 5 mg/Nm³. Even if ammonia slip is not restricted by regulation ammonia slip should not be higher than 5-10 mg/Nm³ as ammonia may cause a light odour of the flue gas residues.

When operating the SNCR process with emission values around 150 mg/Nm³ the ammonia slip is normally 1-5 mg/Nm³. If the emission value is required much lower than 150 mg/Nm³ it is normally not possible to get guarantees on ammonia slip below 10 mg/Nm³.

The SNCR process is typically chosen on incineration facilities where there is no regulatory or financial incentive to reduce NO_x below emission limits around 150-200 mg/Nm³.

Except for the injection nozzles, the dosing system and the ammonia storage the SNCR system does not require much space.

SCR

The reaction between NO_x and the injected NH_3 takes place on a catalytic surface. Due to the catalyst the reaction can take place at a lower temperature normally around 250 °C, however, references in the temperature interval between 180-350°C are available.

The acceptable temperature is among other depending on the content of dust, SO_2 and HCl in the flue gas and hereby depending on whether the SCR is placed before or after the flue gas treatment plant – after the flue gas treatment system the temperature can be lower as the content of pollutants is reduced significant.

Contrary to the SNCR process ammonia has to be added to the process in a small surplus only. For reducing the amount of NO_x with 80% some few percent (3-5%) ammonia more than the stoichiometric amount has to be added compared to 2,5 times for the SNCR.

The consumption of ammonia water is below 1,5 kg 25% ammonia water per ton (metric) waste by reduction of NO_x from approx. 400 mg/Nm³ to approx. 180 mg/Nm³. The ammonia slip is negligible.

As mentioned above SCR is typically used if there is a regulatory or a financial incentive to reduce the NO_x emission and normally SCR processes are operated with emission levels between 20-70 mg/Nm³ and in some cases below 20 mg/Nm³ as is the case at many WtE facilities in Sweden where a high NO_x -tax is the driver.

At WtE facilities the SCR process is typically introduced after the flue gas is treated and SO_2 and SO_3 is reduced to prevent precipitation of ammoniahydrogensulphate as well as the lifetime of the catalyst is prolonged when Hg, HCl and dust is removed before the catalyst.

For the tail-end SCR process, where the flue gas has been treated and the amount of pollutants is reduced the process might be carried out at a lower temperature without too high risk for precipitation. Some plants have tested temperature from 180-220°C but the experience is so far not sufficient and Ramboll recommends temperature at around 220-250°C.

A disadvantage with the tail-end SCR process is that the flue gas temperature after the APC system is lower than the temperature required for SCR and a reheating is required. Reheating is normally done by usage of heat exchanger where the ingoing flue gas to the SCR-process is preheated with the flue gas leaving the SCR as illustrated in figure 3. The need for

additional heating is hereby reduced to approx. 25 °C which can be done by the usage of drum steam or saturated steam from the turbine.

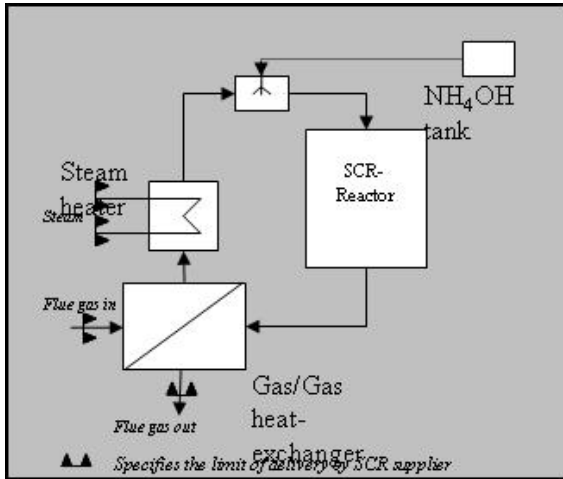


Figure 3. Typical Configuration of the SCR System

Alternatively the SCR process can be placed before the APC plant. However, the risk for clogging is high and Ramboll recommends to place an ESP before the SCR to prevent too high dust concentration to the SCR. Operating experience from the few WtE facilities operating high SCR placed before the APC plant shows that the life-time of the catalyst is reduced significantly.

The SCR system consists of a heat exchanger, a steam re-heat system, the catalyst (SCR) and the ammonia storage and dosing system. The dimensions depend on the actual supplier. Typical dimensions for a 600 tpd facility are given in Table 2.

	Heat-exchanger	Steam re-heat	SCR
Length	8,5 m	6 - 7 m	6 - 7 m
Height	5 m	1 - 1,5 m	12 - 19 m
Width	6 m	4 m	4,5 - 8,5 m

Table 2: Typical dimensions for the SCR-system

The material and the structure of the catalyst shall be designed in cooperation with experienced vendors of the SCR as the design of the SCR is crucial for a good operation and a long lifetime of the system.

The active component in catalyst is among others V_2O_5 .

A wide structure of the catalyst will reduce the risk for clogging but contrary a narrow structure of the catalyst will increase the surface of the SCR and hereby increase the efficiency of the SCR.

A typical example of a catalyst is illustrated in figure 4.

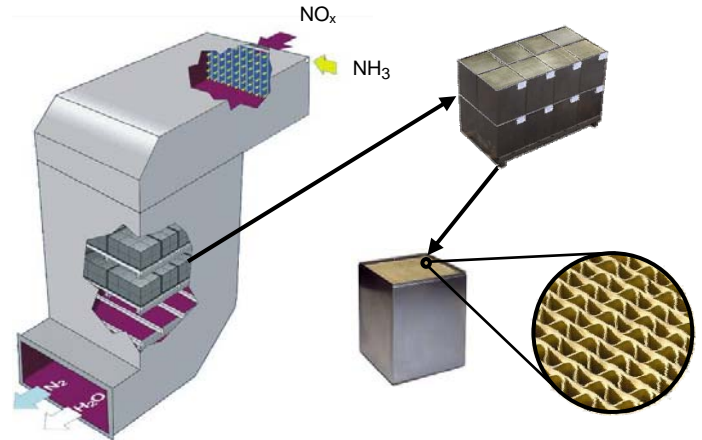


Figure 4. Typical SCR System. Source: Haldor Topsoe

ADVANTAGES AND DISADVANTAGES OF SCR AND SNCR

The advantages and the disadvantages of SCR and SNCR are summarized in the matrix in Figure 5 below.

	SNCR	SCR
Advantages	<ul style="list-style-type: none"> • Simple technology • Lower investment cost • Many reference plants • Low foot-print 	<ul style="list-style-type: none"> • Low consumption of ammonia • Many reference plants • Emission levels below 100 mg/Nm³ can easily be achieved • Side effect – dioxin reduction
Disadvantages	<ul style="list-style-type: none"> • Higher ammonia consumption • Risk for ammonia slip • Difficult to get guarantees from vendors below 100-150 mg NO_x/m³ • Require high control of the temperature 	<ul style="list-style-type: none"> • High investment costs • Energy consumption for reheat • Relative large foot-print

Figure 5: Matrix illustrating advantages and disadvantages of SCR and SNCR.

OPERATIONAL AND INVESTMENT COSTS

The investment cost for installation of DeNO_x is significant higher for SCR compared to SNCR. The consumption of ammonia is higher for SNCR compared to SCR, but is caught up by the requirement for re-heat for the SCR (tail-end).

Various set of emission levels have been used for comparing NO_x reduction by SNCR and SCR:

- 150 mg/Nm³
- 100 mg/Nm³
- 70 mg/Nm³ (only guaranteed with SCR, but is included as it is a typical operation level if SCR is installed)

Based on Ramboll's experience the cost – investment of operational – is calculated over a 20 years period and is summarized in Table 3.

	SCR 90 ppm _{dv} @7% O ₂	SCR 50 ppm _{dv} @7% O ₂	SNCR 90 ppm _{dv} @7% O ₂
Total Capital Cost (mill USD)	8-9,5	8-9,5	1,8
Annual Cost (mill USD)			
- Capital cost, 5% 20 years	0,65-0,75	0,65-0,75	0,14
- Extra maintenance	0,07	0,07	
- Consumables - NH ₃	0,04	0,05	0,06
- Consumables - additional electricity for ID-fan	0,06	0,06	
- Lost electricity revenue from steam use to reheating	0,20	0,20	
Total Annual Cost (mill USD)	1-1,12	1-1,13	0,20
Cost pr. ton of waste (USD/t)	5,6-6,2	5,7-6,30	1,13

Table 3. Investment Cost and Operation Cost for SCR and SNCR

As shown in Table 3 the cost per ton of waste is approximately 5-6 USD/ton.

OPERATION EXPERIENCE

DeNO_x processes – both SNCR and SCR - have been used with good experience in Europe for many years.

In Denmark all DeNO_x systems are based on the SNCR technology as the emission limit is 200 mg/Nm³ and as there is no incentive reducing the emission further.

In Sweden the high NO_x tax make the SCR system feasible and most of the new WtE plants are equipped with SCR systems operated with very low emission levels – often below 20 mg/Nm³. A very good example is the plant in Malmö, SYSAV, where the plant has operated a SCR system since 2003. Based on the good experience also the new line taken into operation in 2008 is equipped with SCR. The plant is shown in figure 6.

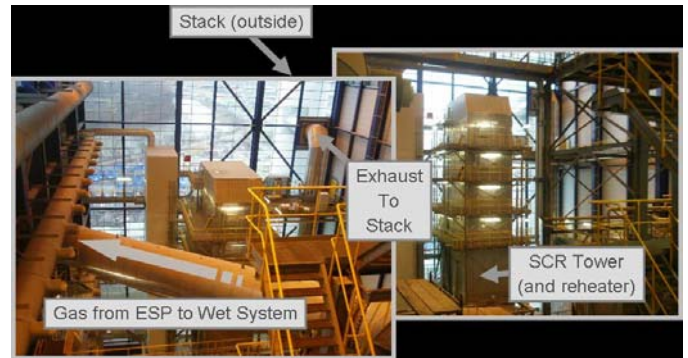


Figure 6. SCR at SYSAV, Malmö in Sweden.

In Norway the regulation can be fulfilled with SNCR. However, a high emission tax has enforced the larger plant to install SCR.

Austrian WtE facilities have to fulfil a low emission level and have had SCR for many years. Especially the plant in Vienna, Spittelau, has had SCR for 17 years. The experience with the catalyst itself is good, however, the design of the preheat-system as well as the possibility for manual inspection and cleaning of the catalyst is not optimal. For new SCR-systems these problems have been mended and new installations operate satisfactory.

In Germany the emission limit for NO_x has been introduced by the national regulation before the EU-regulation was implemented. Most of the German plants are equipped with SCR and have a long-time experience with SCR. Most of the SCR plants operate without problems, however, some of the older plants realize problems mainly due to clogging problems. For new facilities the experience is satisfactory as the design and the reliability of the SCR has been increased significantly. Some German plants have tested the high temperature-high dust solution and have experienced clogging problems.

In Italy most of the plants are running SNCR processes. Especially ASM Brescia has experienced good operation and very low emission levels with SNCR. However, the Italian regulation is becoming more stringent especially in the northern part of Italy and ASM Brescia is testing a high temperature-high dust solution at one of their three lines with the purpose of achieving even lower NO_x values and reducing the ammoniaslip. The preliminary results show acceptable operation but reduced lifetime of the catalyst.

Most of the WtE facilities in Switzerland is equipped with SCR and have experienced good operation. The SCR is commonly a tail-end solution but also good experience from operation of a high temperature-low dust SCR solution.

In France and Belgium both SNCR and SCR processes are installed, both solutions are operating without problems.

In the Netherlands most WtE facilities – and all new facilities - are equipped with SCR due to the low emission limit.

To sum up it can be concluded that the experience with both SNCR and SCR is extensive and the operation with both systems are good. Some of the old SCR installations have experienced problems mainly due to insufficient experience in the design and cleaning and inspection is difficult. Also clogging and poisoning of the catalyst have created problems for the old plants, for the more recent plants the quality of the catalyst material and a better knowledge of the chemical reaction and the temperature have improved the operation significant and the SCR is today in Europe considered a well-proven and stable process.

WILL SCR INSTEAD OF SNCR SIGNIFICANTLY REDUCE THE OVERALL NO_x EMISSION FROM THE POWER INDUSTRY?

The Danish EPA has estimated the NO_x emission from the Danish power production in year 2020. Based on these figures the NO_x emission from the WtE industry will by using SNCR and an average emission at 200 mg/Nm³ contribute to 17% of the total NO_x emission from the power industry.

By introducing SCR and a NO_x emission at 70 mg/Nm³ the NO_x emission from the Danish WtE facilities will be reduced from 17% to 6%.

low NO_x is to a higher extent seen as the driver for introducing SCR in the US.

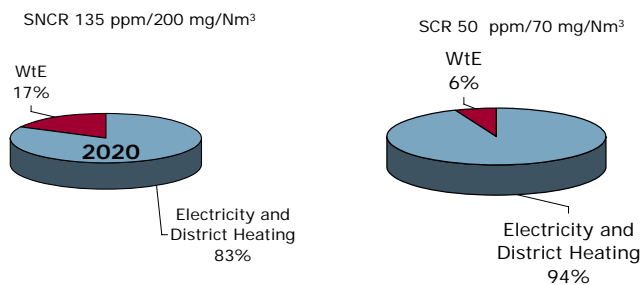


Figure 7. NO_x contribution by WtE in year 2020 by using SNCR and SCR respectively. Source: Danish EPA

Whether or not the reduction of NO_x from 17% to 6% is significant enough to justify mandatory SCR over SNCR is very much a political decision that is at present being discussed among the EU member countries.

As the WtE facilities in the US do not contribute as much to the national power production as in Denmark, where more than 3% of the national electricity consumption is generated by WtE facilities the reduction of NO_x from WtE will not significantly reduce the national NO_x emission. However regional goals for