Application of SNCR Technology in Coal-Fired Boilers (225 MW_{el}) Better Performance and Cost Saving with Selective Cooling

Bernd von der Heide
Mehldau & Steinfath
Umwelttechnik GmbH
Germany

1. Introduction

The SNCR process was introduced in the eighties of the last century and became the Best Available Technology (BAT) for smaller and medium sized combustion plants like WtE plants approximately ten years later. For larger coal-fired power plants, however, the SNCR process was not considered sufficient to maintain the required NO_x reduction at all boiler loads and operating conditions. Thus the SCR technology was applied in most cases.

While both technologies, low NO_x combustion and SNCR, developed rapidly, especially after the turn of the millennium, the application of the SNCR process became a technically and economically viable option to minimize the NO_x emissions also in larger power plants.

This paper addresses the different approaches in two power plants in Poland where similar boilers (Type OP 650) with a capacity of 225 MW_{el} are installed. Operating experiences show that with the latest developments and improvements the current NO_x levels imposed by the regulators can be assured, and that there is also potential to comply with expected more stringent requirements.

2. Influences of Design and Operating Conditions on SNCR Performance

The basis of the SNCR technology is to inject the reagents homogenously into the optimum temperature window and to mix them thoroughly with the flue gases. However, in most cases this is not easy to accomplish since there are several major parameters defining the location and accessibility of the optimum temperature window, which are for example:

- The boiler design
- The design of the combustion chamber
- The position of the heat exchangers
- The design and configuration of the burners (profile of temperatures, NO_x, flue gas velocities)
- The operating conditions in the boiler
- The type of fuel
- The reagent – urea solution or ammonia water

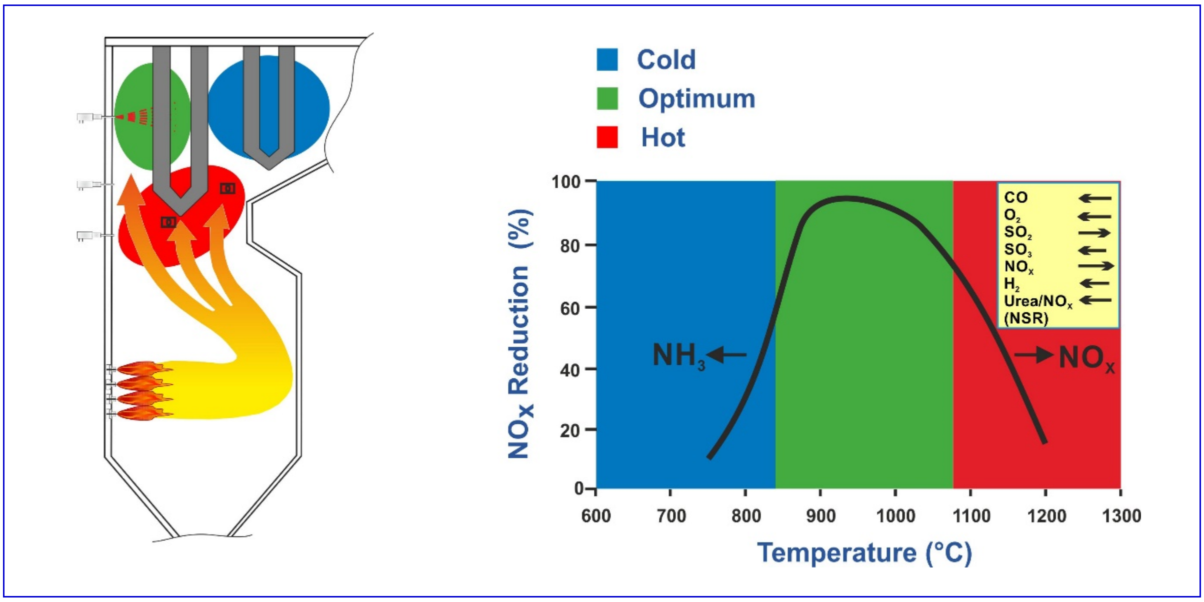


Figure 1: Typical temperature distribution in a coal-fired two pass boiler

Due to the size of power boilers, the problems that have to be solved by suppliers of SNCR technology are more complex than compared to grate-fired boilers. Especially at full load, temperatures tend to be too high in the areas that are free of built-in components. Consequently, at the furnace exit, the reagent will be burnt to NO_x at higher boiler loads. The temperatures necessary for NO_x reduction are often found between the heat exchangers (**Figure 1**), which are difficult to access or not accessible to injection at all. In addition to this, it is practically impossible to measure or determine the velocities and directions of the flue gases.

3. SNCR Application in Coal-Fired Boilers in Poland

The results of operating experiences with coal-fired boilers in Poland prove that even minor differences in the design of the boilers and the configuration of the burners may have major influence on the flue gas flow and temperature distribution, and consequently on the efficiency of the SNCR process.

By far the best results could be achieved in boilers with corner-firing, like in the power plant in Polaniec, Poland, where during trials reduction rates of close to 60 % were realized. In corner-fired boilers the flue gases are circulated, which has several positive effects on the SNCR process as opposed to front-fired boilers or boilers with boxer-firing. In a corner-fired boiler, the flue gases have a lower temperature when entering the heat exchangers, the temperature imbalances are less extreme and the formation of flue gas streams is reduced.

With computer simulations it is possible to provide a rather detailed description of all parameters relevant to the SNCR process, like temperature profile, direction and velocities of the flue gases, distribution of components (NO_x, CO, O_2 etc.). This offers further potential to improve the performance of SNCR.

4. Location A – SNCR with In-Furnace Lances

In the power plant at Location A in Poland, six coal-fired boilers type OP 650 (**Figure 2**) are operated with front-firing. After exchanging the burners and retrofitting the supply of combustion air, a commercial SNCR plant was installed in one of the boilers. Earlier operating experiences with other boilers and the results of the previous tests with similar boilers were applied as basis for the design of the SNCR system.

The design includes three injection levels with lances for the injection of urea solution which can be activated individually, enabling the plant to react to changes of load and temperature. Due to the extreme temperature imbalances of up to 200 K, which had been measured at the beginning of the design phase, an acoustic temperature measurement system (agam) with two levels was installed. The second agam level allows for a more precise temperature measurement near the injection lances and is used to determine the temperature gradient between the two agam levels. The first SNCR plant (K2) was commissioned in March 2012 and handed over to the customer shortly after. Since then the plant has been in continuous operation and runs smoothly to the full satisfaction of the customer. The last SNCR (K5) was handed over in December 2016.

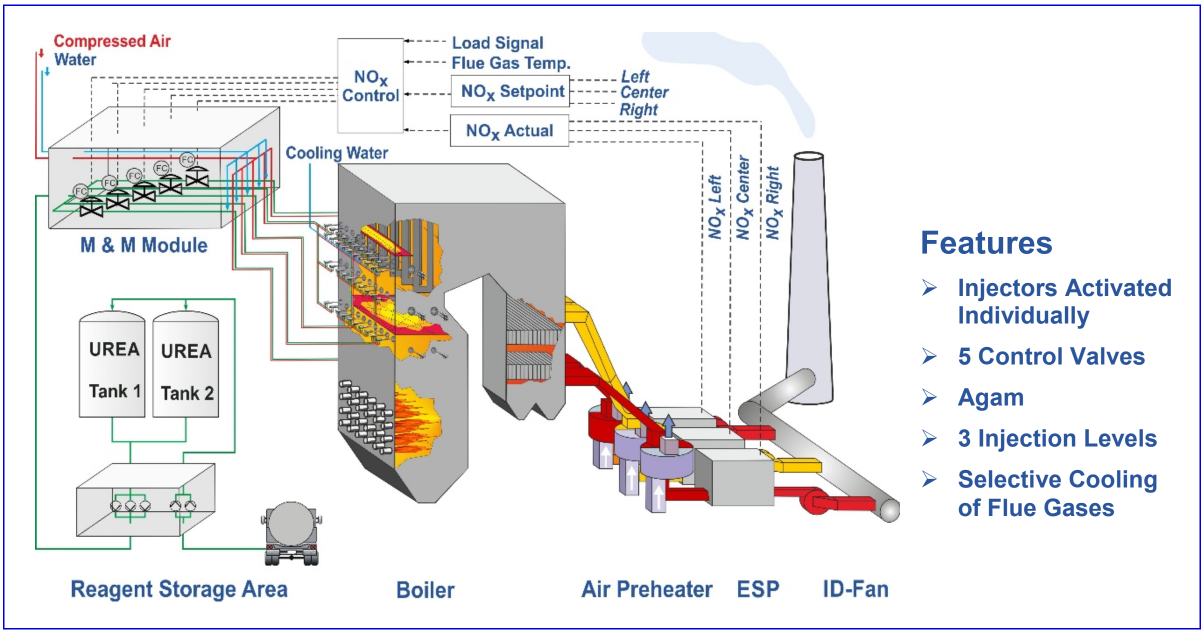


Figure 2: Flow diagram of coal-fired boiler OP650 with SNCR

After commissioning of the first boiler, the flue gas temperatures at full load were found to be higher than in measurements prior to the design of the SNCR. There were also considerable peaks and imbalances in the temperature profile and NO_x raw gas concentration. A further challenge in these boilers is that deposits on the heat exchangers accumulate so much that the flue gas temperature increases by up to 300 °C (**Figure 3**).

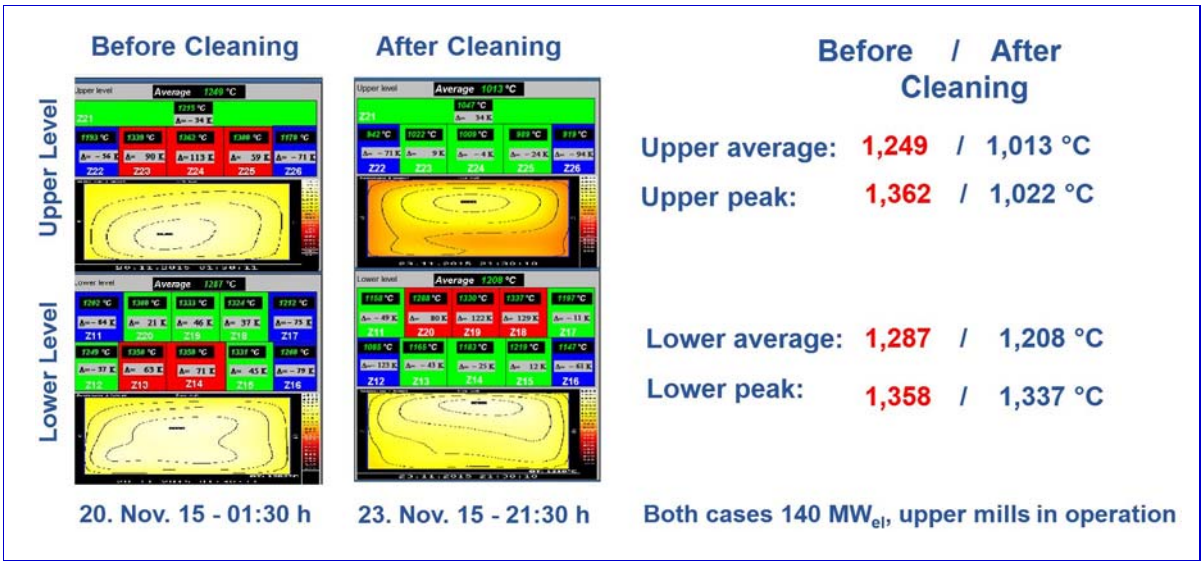


Figure 3: Effect of boiler cleaning on flue gas temperatures

These deposits also have an impact on the direction and velocity of the flue gas flow. Therefore, the upper injection level in the second boiler was moved up higher, to a place where the temperatures are colder. Although the guaranteed NO_x levels in the first boiler had been met, an optimization process was started in close cooperation with the customer, in order to analyze the results and find measurements to improve the performance of the SNCR further. The first step was to install three NO_x control valves. This resulted in a lower ammonia slip both in the flue gas and the ash, and a reduction of the ammonia water consumption.

Combined with the primary measures, the guaranteed NO_x levels of < 200 mg/Nm³ are reached at all operating conditions. The average NH_3 load of the fly-ash measured in the period from January 1, 2013 to July 30, 2013 was 37 mg/Nm³ (**Figure 4**).

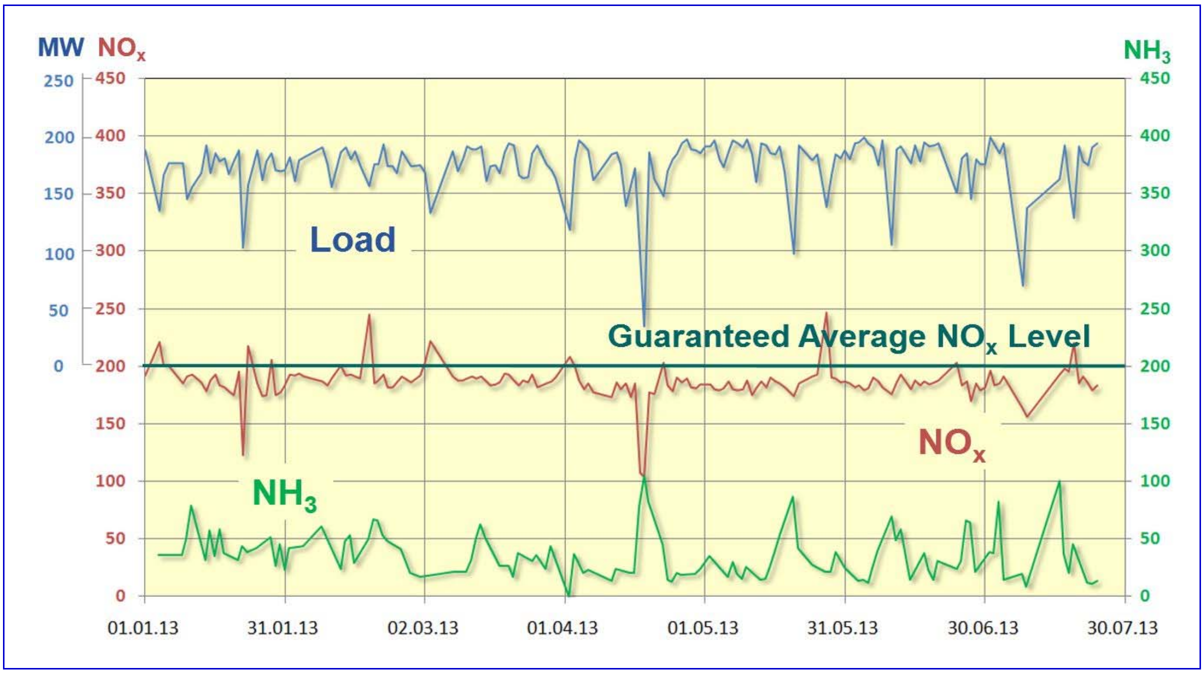


Figure 4: Long-term performance data of SNCR in coal-fired boiler (225 MW_{el})

It is expected that the required NO_x limits in the EU will be decreased to 150 or 175 mg/Nm³ in the future. Since this cannot be guaranteed with the present design for all operating conditions, other alternatives for the boilers in Location A had to be looked for to improve the performance of the SNCR.

If flue gas temperatures are too hot for the SNCR technology in those areas which are accessible to the injection of reagents, one obvious option is to cool down the flue gases with water to the optimum temperature. In larger boilers where the reagents are practically always injected at right angles into the flue gas flow, the installation of an additional injection level which can be operated with cooling water alone, when needed, has proven to be successful in continuous operation. With this concept cooling water is only applied when temperatures are too high. At lower loads respectively temperatures, the water is switched off. The droplet spectrum for the injection of reagents is not changed. However, the disadvantage is that temperature imbalances may lead to higher ammonia slip, because the cooling also takes place in areas where cooling is not needed.

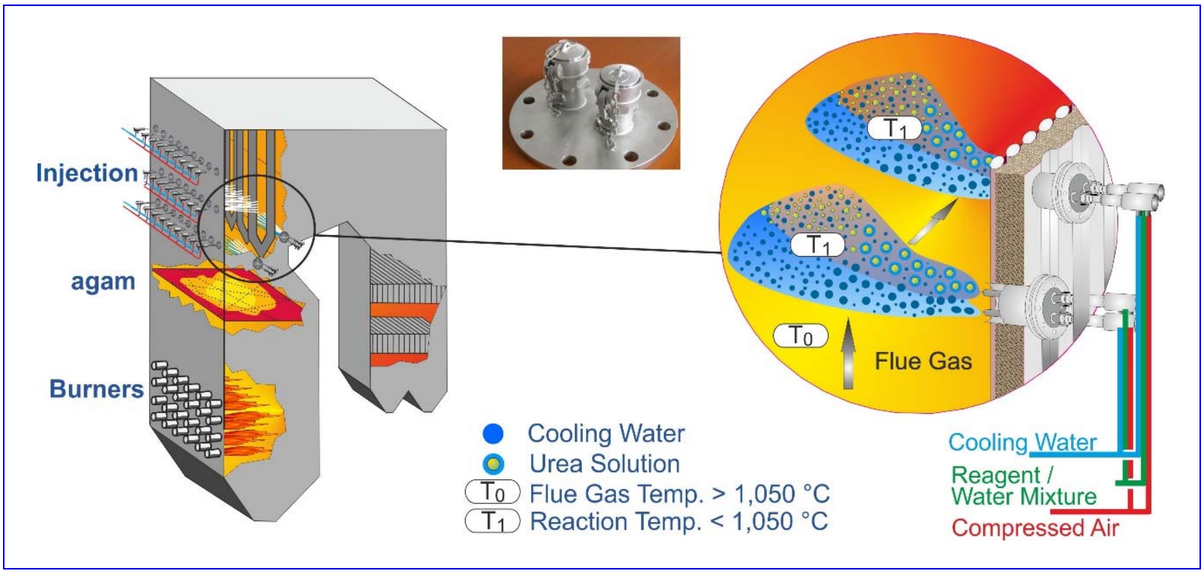


Figure 5: ***Selective Cooling*** **of flue gases for coal-fired boilers**

In other places, good results have been achieved with *Selective Cooling* of the flue gases which also requires an additional injection level for cooling water beneath the upper injection level. However, instead of injecting water into the whole level, cooling water is injected only in those areas which are too hot **(Figure 5)**, i. e. depending on the temperature profile individual lances or a group of lances are activated.

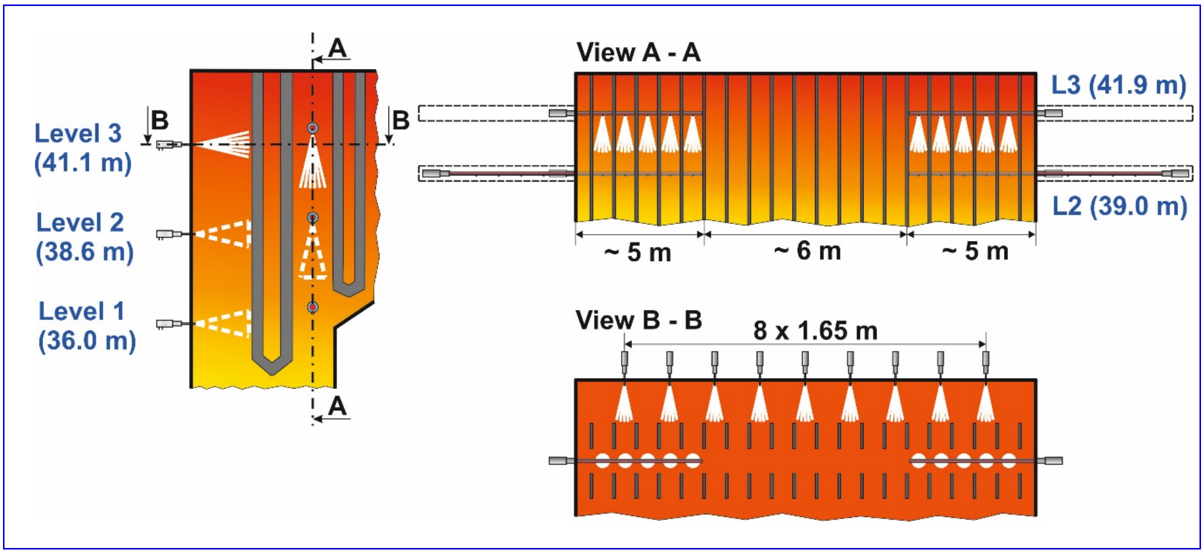


Figure 6: **Configuration of injectors at front wall and *in-furnace lances***

However, since flue gas temperatures at the furnace outlet in Location A reach 1,350 or even 1,400 °C at full load, the application of *Selective Cooling* is not a reasonable solution in this case because the quantity of cooling water required for cooling the flue gases down to the effective temperature window of approx. 980 to 1,050 °C is so high that the efficiency of the boilers would be affected too much. This also means that about 50 % of the flue gas are not usable for NO_x reduction because of too high temperatures.

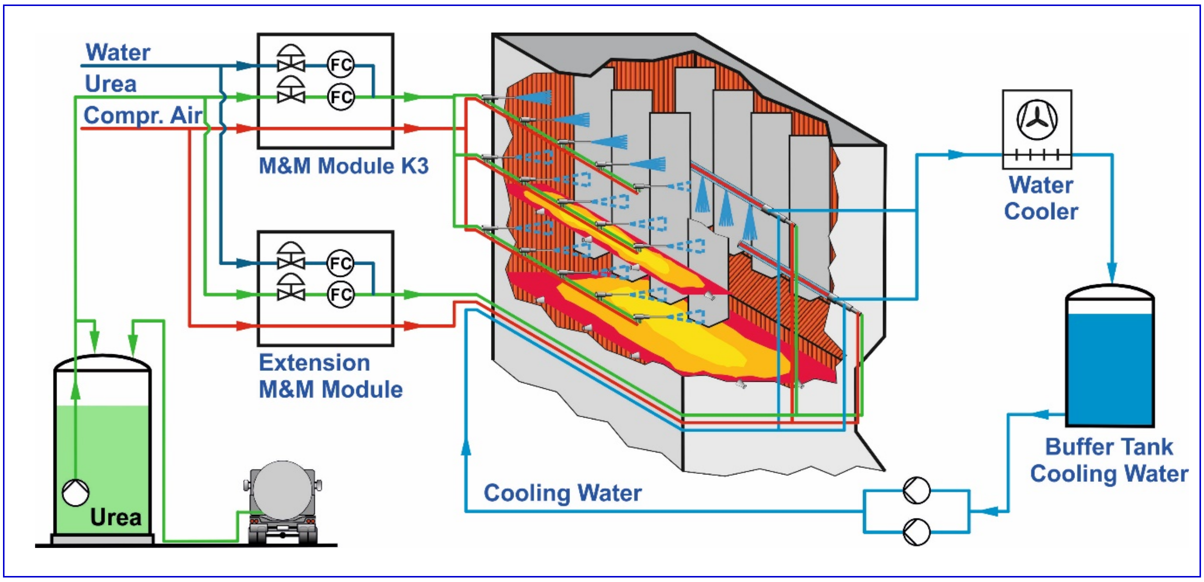


Figure 7: **Flow diagram with injection from front wall and *in-furnace lances***

In order to inject reagent in the missing flue gas a different approach has been tested. Assuming that the flue gas temperatures between the heat exchangers are more favorable, two SNCR *in-furnace lances* with a length of only four meters have been installed in each side wall of the boiler in the path between the first and second super heater (**Figures 6, 7, 8**). The distance between the two side walls of the boilers is 16 m. **Figure 9** shows the temporary mixing and metering module for the *in-furnace lances* and the module for cooling water.

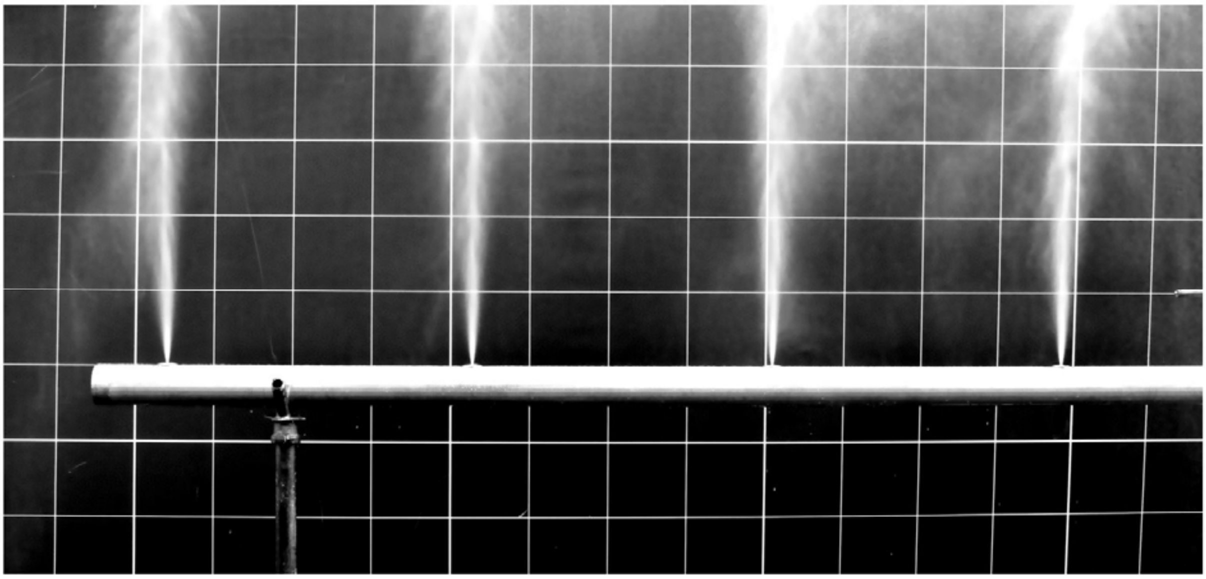


Figure 8: **Reagent injection – Nozzle configuration of in-furnace lances**

Since one lance of 4 m length already weighs approx. 150 kg it is very difficult to install the lances manually into the boiler wall and take them out again (**Figure 10**). It was assumed that test results with those short lances would provide sufficient information to estimate the additional potential for performance in commercial operation if longer lances are used, which would be pushed into the boiler and retracted automatically on devices similar to soot blowers.

Figure 9: Mobile mixing and metering module **Module for cooling water**

Figure 10: Location A – Installation of in-furnace lances

The test results are very positive and show that the present NO_x reduction can be increased to more than 100 mg/Nm³ in total if *in-furnace lances* are used in addition to the injection from the front wall (**Table 1**). In case four *in-furnace lances* are used and the lengths of the lances are extended to cover the whole distance between the boiler walls, the NO_x limits which are expected in the future, can be reached. It also could be an option to operate the boiler with higher NO_x baselines in order to decrease the risk of causing corrosion on the walls of the combustion chamber.

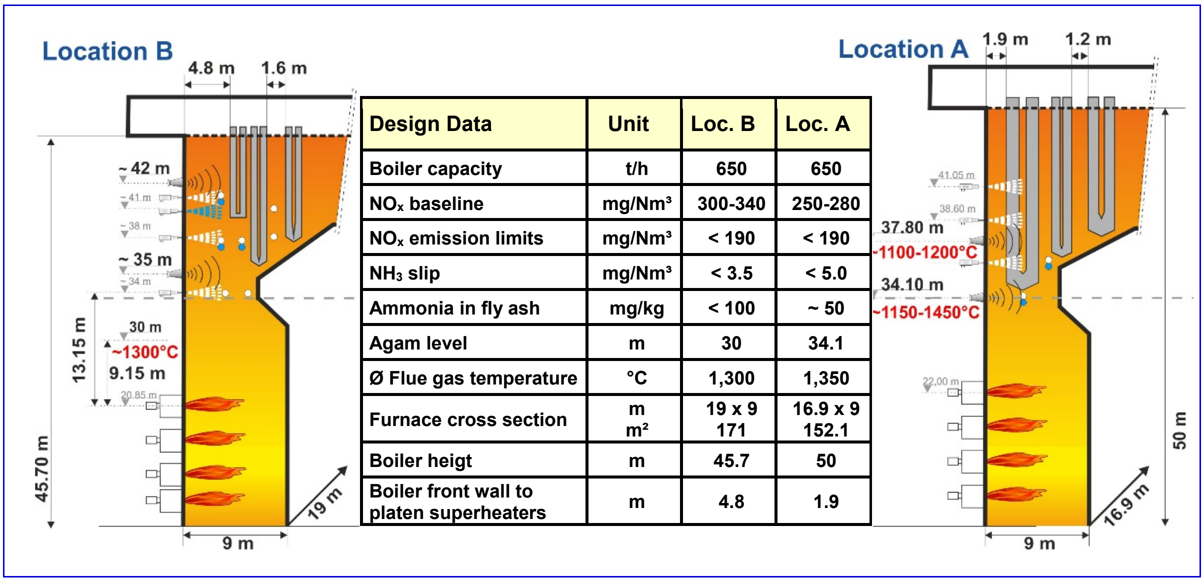
Selected Test Results	Urea (32%) Flow [l/h]		Water Flow [l/h]		Configuration of IFL (nozzle Ø, L, direction of spray)	NO_x [mg/m³]		NO_x Reduction [mg/m³]
	FWL	IFL	FWL	IFL		Raw Gas	Clean Gas	
1	200	200	1000	400	Ø 3.5 mm L3 ⬇	247	178	69
2	200	0	1000	0	-	255	212	43
3	0	200	0	400	Ø 3.5 mm L3 ⬇	272	238	34
4	0	200	0	1400	Ø 6.0 mm L3 ⬇	254	200	54
5	0	200	0	1400	Ø 6.0 mm L2 ⬆	260	220	40
6	180	180	1020	1420	Ø 6.0 mm L2 ⬆	255	168	87

IFL	In-Furnace Lance	🟦	IFL, FLW	combined
FWL	Front Wall Lance	🟥	FWL	only
L (L2, L3)	Injection Level	☐	IFL	only

Table 1: Test results with different lance configurations

5. Location B – SNCR with Selective Cooling

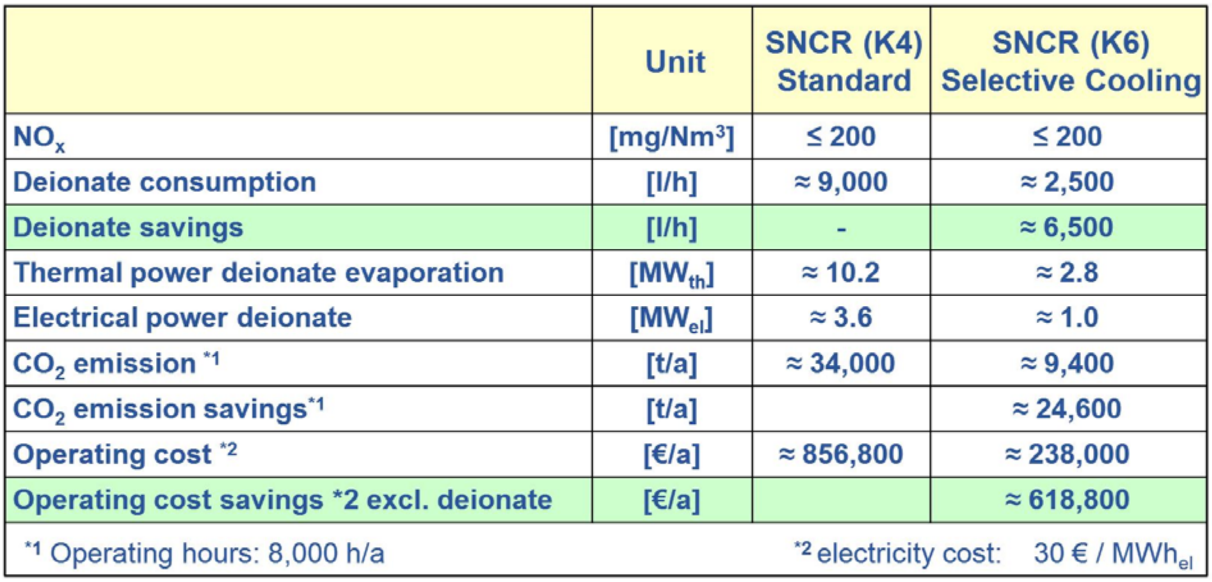
In April 2015, M&S was awarded with the contract to install four SNCR plants in the power plant of Location B. The boilers are of the same type as in Location A, OP 650, with a capacity of 225 MW_{el}. However, some design features are different as shown in **Figure 10** and have a considerable impact on the performance of SNCR as can be seen in **Table 2**.



Design Data	Unit	Loc. B	Loc. A
Boiler capacity	t/h	650	650
NO_x baseline	mg/Nm³	300-340	250-280
NO_x emission limits	mg/Nm³	< 190	< 190
NH_3 slip	mg/Nm³	< 3.5	< 5.0
Ammonia in fly ash	mg/kg	< 100	~ 50
Agam level	m	30	34.1
Ø Flue gas temperature	°C	1,300	1,350
Furnace cross section	m m²	19 x 9 171	16.9 x 9 152.1
Boiler heigt	m	45.7	50
Boiler front wall to platen superheaters	m	4.8	1.9

Figure 10: Design data of Location A and Location B

In Location B, the arrangement of the heat exchangers is much more favorable than in Location A. The width of the boiler of 19 m in Location B compared to 16.9 m in Location A, and the distance from the boiler front walls to the platen super heaters (4.8 m in Location B vs. 1.9 m in Location A) leave almost three times more space for the reaction of the reagent with the NO_x in the flue gas (91.2 m² vs. 32.1 m²) in the upper injection level, which is relevant for the SNCR performance at higher loads. Furthermore, the larger cross section of the furnace in Location B (171 m² vs. 152.1 m²) result in lower flue gas velocities, lower flue gas temperatures at the reaction locations, and longer residence time for the NO_x reduction.



	Unit	SNCR (K4) Standard	SNCR (K6) Selective Cooling
NO_x	[mg/Nm^3]	≤ 200	≤ 200
Deionate consumption	[l/h]	≈ 9,000	≈ 2,500
Deionate savings	[l/h]	-	≈ 6,500
Thermal power deionate evaporation	[MW_{th}]	≈ 10.2	≈ 2.8
Electrical power deionate	[MW_{el}]	≈ 3.6	≈ 1.0
CO_2 emission *1	[t/a]	≈ 34,000	≈ 9,400
CO_2 emission savings*1	[t/a]		≈ 24,600
Operating cost *2	[€/a]	≈ 856,800	≈ 238,000
Operating cost savings *2 excl. deionate	[€/a]		≈ 618,800

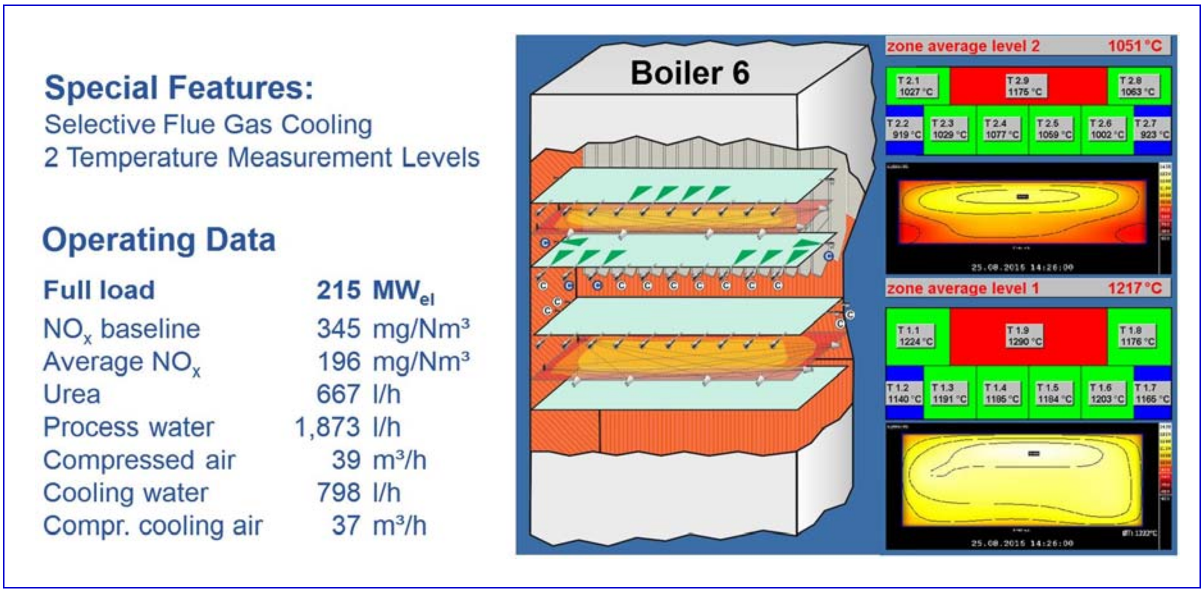
*1 Operating hours: 8,000 h/a *2 electricity cost: 30 € / MWh_{el}

Table 2: Comparison of standard SNCR vs. SNCR with *Selective Cooling* regarding water consumption

The concept for boiler K6 was elaborated based on the boiler design, the expected lower flue gas temperatures, the performance of the standard SNCR which had been installed and commissioned at boiler K4, and the results and experiences in Location A. **Figure 11** shows the mixing and metering modules of Location B and the injection lances.

Figure 11: Location B – Mixing and metering module **Injection lances**

The significant difference to Location A is that injection lances for *Selective Cooling,* installed below the highest injection level for the reagent, could be utilized because the flue gas temperatures in this position were lower than in Location A and the space between the front wall and the first super heater was larger, which resulted in a much better performance of the SNCR system.



Special Features:

Selective Flue Gas Cooling

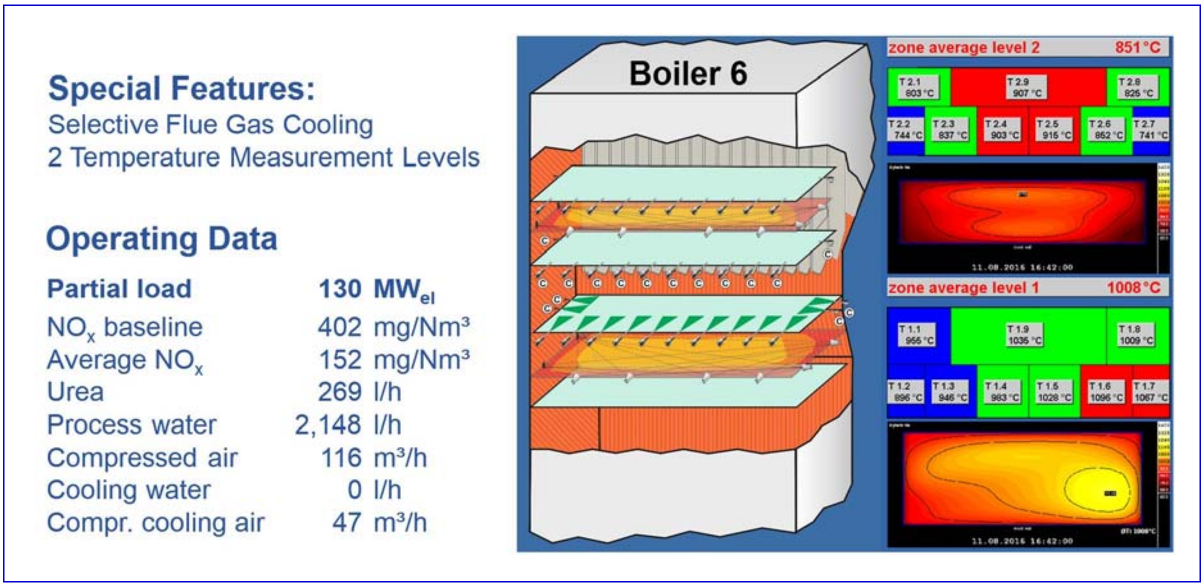
2 Temperature Measurement Levels

Operating Data

Full load	**215 MW_{el}**
NO_x baseline	345 mg/Nm³
Average NO_x	196 mg/Nm³
Urea	667 l/h
Process water	1,873 l/h
Compressed air	39 m³/h
Cooling water	798 l/h
Compr. cooling air	37 m³/h

Figure 12: ***Selective Cooling*** **of flue gases - Operating data at full load (215 MW_{el})**

Figures 12 and 13 show the performance of the SNCR at boiler loads of 215 MW_{el} and 130 MW_{el} and during the two weeks reliability run (**Figure 14**). All guarantee values were achieved at all loads.



Special Features:

Selective Flue Gas Cooling

2 Temperature Measurement Levels

Operating Data

Partial load	**130 MW_{el}**
NO_x baseline	402 mg/Nm³
Average NO_x	152 mg/Nm³
Urea	269 l/h
Process water	2,148 l/h
Compressed air	116 m³/h
Cooling water	0 l/h
Compr. cooling air	47 m³/h

Figure 13: ***Selective Cooling*** **of flue gases - Operating data at partial load (130 MW_{el})**

It is remarkable that the total water consumption which was an important issue during contract negotiations is approximately 1,000 l/h lower than the guaranteed maximum of 3,500 l/h and ca. 6,500 l/h lower than the consumption of the standard SNCR installed at boiler K4. These results demonstrate impressively that the *Selective Cooling* is superior to other SNCR technologies for the discussed type of power boilers and that a significant amount of operating cost can be saved.

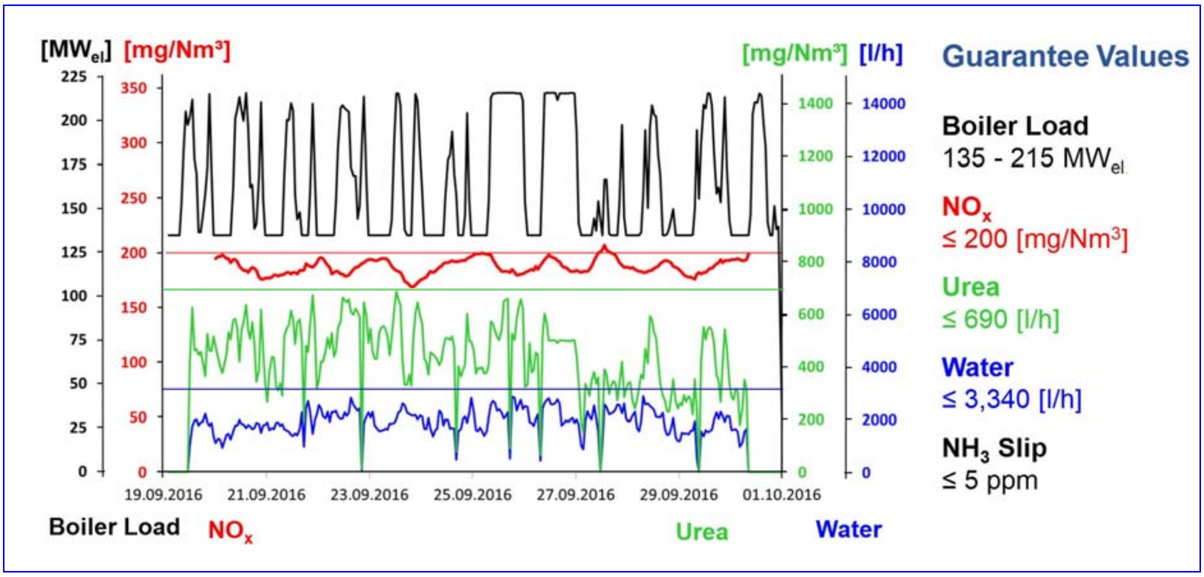


Figure 14: Performance data during two-week reliability run at Location B

6. Summary and Outlook

In smaller combustion plants, e. g. those which burn waste or biomass, the SNCR process represents an industry standard and state-of-the-art method. In the meantime, operating experiences in large combustion plants with a capacity of > 200 MW_{el} have shown over the past few years that SNCR can safely and reliably achieve the NO_x level < 200 mg/Nm³ which is enforced by EU legislation in 2016. Different injection concepts can be used separately or in combination.

The initial results of the newer technologies, like the changing of individual lances, the TWIN-NO_x® process, the *Selective Cooling* and the combination of these methods with primary measures indicate that there is further potential for developments. The next step will be plants with boiler capacities from 300 to 500 MW_{el}.

7. Literature

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