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New Developments of an Effective SNCR Control System Incorporating the NO_x Mass Flow Profile

Bernd von der Heide

The NO_x reduction rates which have been achieved in recent years using non-catalytic technologies (SNCR) have proved to be reliable even in applications which were believed to work only with the more costly SCR process in the past. In the meantime, SNCR has advanced to be the Best Available Technology (BAT) in grate-fired combustion plants.

In power plants, NO_x emissions of 200 to 250 mg/Nm³ in the flue gases can be obtained by applying primary measures alone. An additional reduction below the actual emission level of 200 mg/Nm³ is more and more often realized by using SNCR technology. Due to their size and operating conditions power plant boilers have more complex requirements than Waste-to-Energy plants. Therefore, further steps are needed to catch up with the advances that the SCR process still has over SNCR. This paper describes where the SNCR technology stands today and in which areas there is further potential.

1. SNCR plant technology complying with standards of future legislation

Combustion plants where the first flue gas pass is free of heat exchangers, provide the best conditions for the SNCR technology because the flue gas velocities are low enough to cool down the flue gases in the combustion chamber to the point that the reaction for NO_x reduction is completed before the flue gases enter into the heat exchangers.

These operating conditions are typically found in plants with grate-fired boilers which burn waste, biomass, and coal, as well as in fluidized-bed boilers and smaller coal-fired boilers that are operated in district heating plants, etc.

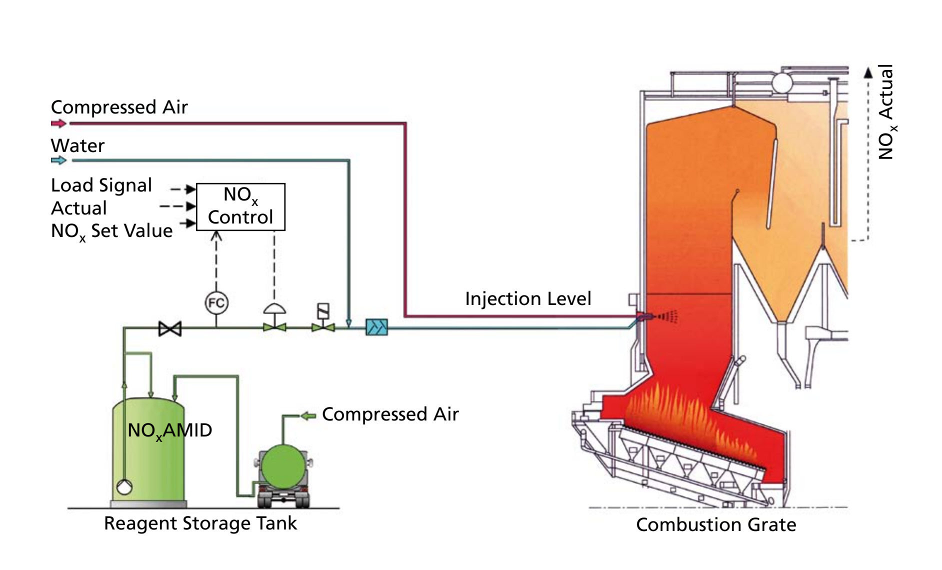

Figure 1: Process flow diagram of a simple SNCR plant

The simplified process flow diagram (Figure 1) shows the function and the scope of supply of an SNCR plant using urea solution as a reagent, typical for combustion plants. These plants are equipped with one or two injection levels which are individually activated depending on boiler load and/or flue gas temperatures.

This concept reliably allows meeting NO_x limits of 120 to 150 mg/Nm³ and NH_3 slip of < 30 mg/Nm³, if the injection lances are arranged in a way that they cover the relatively wide temperature window for injection. Variations in temperature and temperature imbalances, which result in low NO_x reduction in one place can be compensated by a higher NO_x reduction in another place. To prevent temperature variations and imbalances from becoming too big during operation, two injection levels have proven to be best. These two levels are activated depending on the average temperature at the boiler ceiling. Under favorable conditions, i.e. when homogenous fuels are used and boiler loads are constant, clean gas values of < 100 mg/Nm³ can be reached. However, imbalances in the temperatures and the flow of the flue gases can have a negative impact on the NH_3 slip and the consumption of reagent.

In modern SNCR plants, the injection lances are activated individually depending on the flue gas temperatures at the injecting position. After determining the temperature profile, it is divided into sections and can be assigned to a certain lance or group of lances which can then be activated depending on the flue gas temperatures. Even when

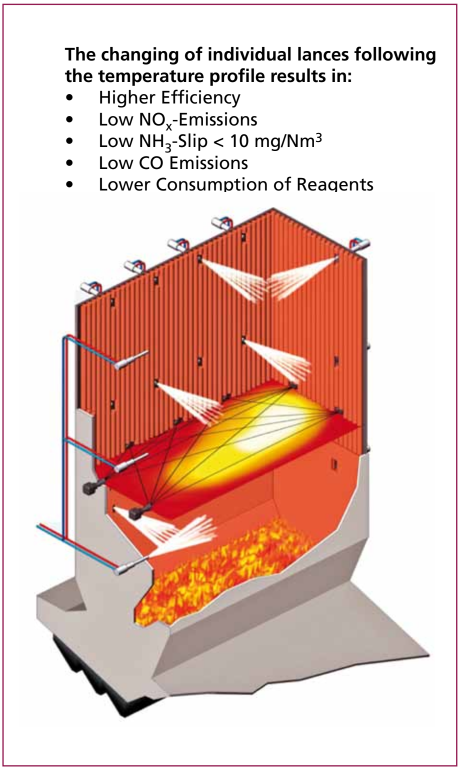

Figure 2: Temperature controlled changing of individual lances

there are sudden changes in the flue gas temperatures this method ensures that the reagent is injected into those areas where optimum results regarding NO_x reduction, NH_3 slip and consumption of reagent (Figure 2) can be achieved.

The results that were measured in continuous operation of several combustion plants show that NO_x clean gas values of < 100 mg/Nm³ and an NH_3 slip of < 10 mg/Nm³ can be guaranteed and even noticeably better results are possible under favorable operating conditions.

In Germany, the Netherlands and Sweden, SNCR plants designed to obtain NO_x levels < 100 mg/Nm³ are being operated since several years and the required emission levels are reliably maintained in continuous operation. NO_x clean gas values and NH_3 slip are particularly low in those plants, which are equipped with acoustic temperature measurement systems (agam) plus three injection levels where each lance can be activated separately.

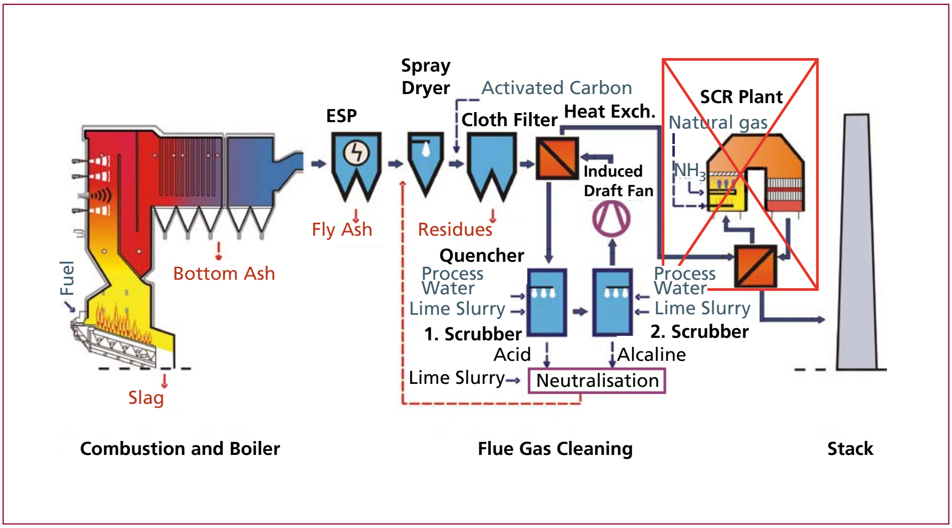

Figure 3: Waste-to-Energy plant Wijster – Replacement of SCR by SNCR

A typical example is the waste-to-energy plant Wijster in the Netherlands where three SCR plants were decommissioned and replaced by SNCR technology. The fuel remaining after separating biowaste, paper, glass, textiles, etc. 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 about 60 MW (Figure 3).

Due to the ambitious objectives (NO_x reduction from about 300 to 350 mg/Nm^3 to < 60 mg/Nm^3 and an NH_3 slip < 10 mg/Nm^3) the installation includes three injection levels with six injectors per combustion line (Figure 4).

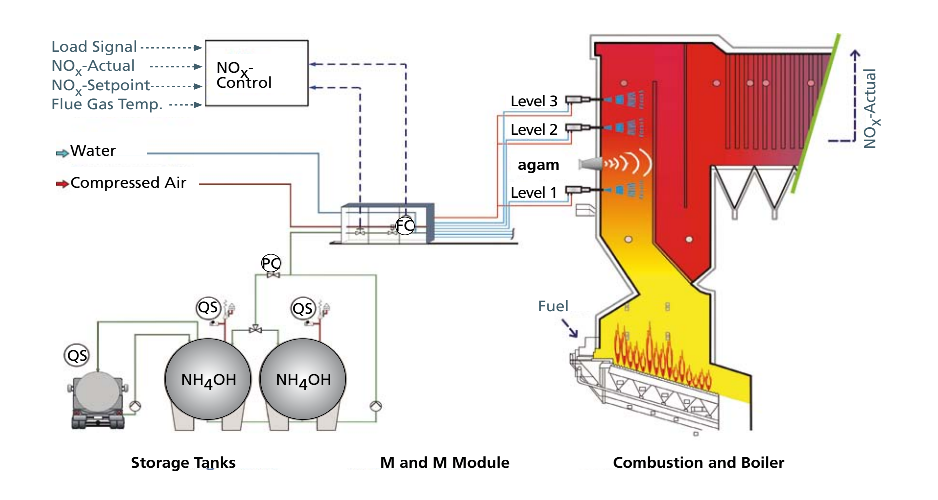

Figure 4: Process flow diagram – SNCR-plant with agam and three injection levels

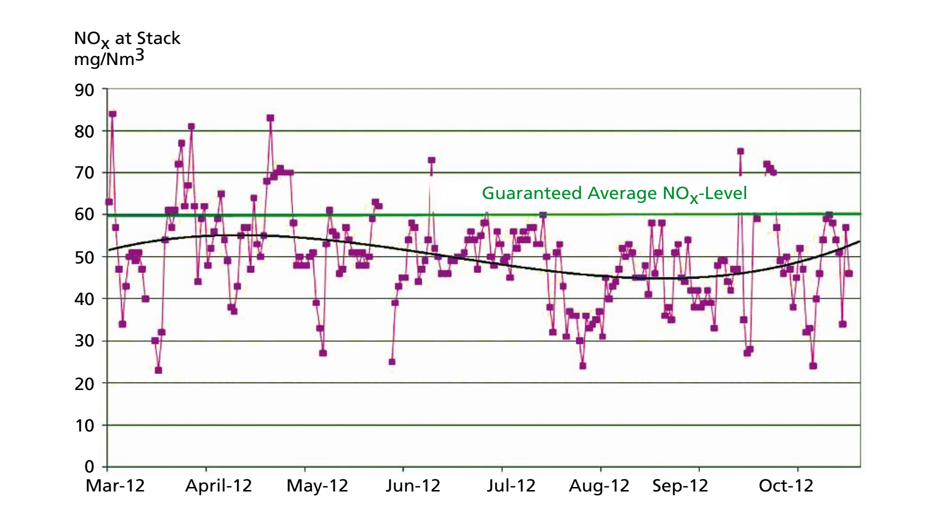

Figure 5: Waste-to-Energy plant Wijster – Long-term daily averages of NO_x

Figure 5 shows the daily NO_x averages of the first SNCR plant and that the emission level of 60 mg/Nm³ dry at 11 percent O_2 could be maintained at all times. During the first six months, the SNCR process achieved an annual NO_x average of < 50 mg/Nm³ dry at 11 percent O_2. This result is comparable with the results of the original SCR plant, which reached annual NO_x averages of 45 mg/Nm³.

After retrofitting (Figure 6) and putting into operation the other two lines, the guaranteed NO_x clean gas values could be met as well. It is remarkable that the NH_3 slip as a by-product of the flue gas cleaning was much lower than expected. In fact, it was so low that the originally foreseen NH_3 stripper for cleaning the waste water became obsolete.

Table 1: Emission levels with SNCR plant

Emissons	Unit	Limit	Operations in three plants
NO_x daily average *	mg/Nm³	100	23 to 84
NO_x annual average	mg/Nm³	65	50
NH_3 daily average downstream the boiler	mg/Nm³		15 to > 22
NO_x raw gas concentration	mg/Nm³	3	0.18

*dry, ref. to 11 % O_2

The results of the first months of operation are listed in Table 1 and Table 2. The daily NO_x averages 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 percent O_2) was achieved. This compares to the SCR plant which reached an annual NO_x level 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.

Apart from the construction of new SNCR plants, many of the existing plants that were designed to comply with the required NO_x levels < 200 mg/Nm³ have to be retrofitted to meet the new NO_x emission standards of < 150 mg/Nm³.

Before Retrofitting After Retrofitting

Figure 6: Control cabinet in Wijster retrofitted for NO_x < 150 mg/Nm³

2. Comparing SCR to SNCR under energy and environmental aspects

The SCR plant in Wijster was installed downstream a wet flue gas cleaning system. 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 m^3/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.

Even hough 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: Operating data – SCR versus SNCR (per line)

Operating Data	**Unit**	**SCR** NH_4OH (24.5 %)	**SNCR** NH_4OH (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 deionised water	m^3/h		1.2
Additional consumption by suction drauhgt	MWh/a	6,100	
Consumption of natural gas	Nm^3/a	6,600,000	

Table 2 demonstrates that operating costs for reducing 1 ton of NO_x are by far higher when using SCR technology than 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.

3. Solutions for a further improved SNCR performance

When the flue gas temperatures are too high in areas that are free of built-in components, enough space has to be provided in the suitable temperature window for the injection and reaction of the reagent(s). This means that the heat exchangers have to be moved or spread, which is usually a very costly undertaking. For new installations, the specific requirements of the SNCR technology should be considered during the design of the boiler, because then the additional cost can be kept to a minimum.

However, if retrofitting is not possible, and especially when several boilers are operated parallely, it might be a possible solution to limit the maximum load of the boilers so that the flue gas temperatures at the exit of the combustion chamber will stay within the effective temperature window. From the process point of view, the local cooling of the flue gases might be an effective and viable alternative. One of the solutions is to provide the necessary operating conditions, i.e. to cool down the flue gases to a level where NO_x reduction is possible under all operating conditions.

Cooling of the flue gases with additional water

Since in Waste-to-Energy plants NO_x levels < 100 mg/Nm³ are state-of-the-art today, the potential for further developments is highest in larger combustion plants, where the flue gas temperatures are too hot in those areas which are accessible for injecting the reagents. A feasible measure could be to increase the quantity of dilution water. However, this has the following disadvantages and is therefore not recommended in most applications:

- Varying quantities of water change the droplet spectrum and consequently the size of the droplets as well as their penetration depth.
- The concentration of the water/reagent-mixture is also changed so that the area where the reduction takes place is shifted.

A continuous operation of the boiler with an increased amount of water is acceptable only as an exception, because vaporizing the water consumes a lot of energy and affects the efficiency of the combustion plant (Figure 7).

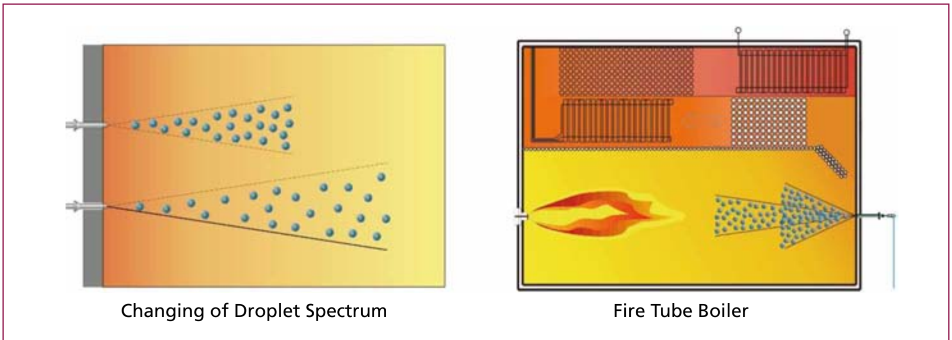

Figure 7: Flue gas cooling by inreasing the quantity of cooling water

Controlling the quantity of water depending on boiler load respectively temperature is a standard procedure and has been practiced since many years in fire tube boilers. The disadvantages mentioned above do not apply to these boilers, as the reagent is injected against the direction of the flue gas flow, and the penetration depth is adjusted in order to follow the changes of the flue gas temperatures.

In larger boilers where the reagent is practically always injected from the side walls across the flue gas flow, the installation of an additional injection level which can be operated with cooling water alone, when needed, has proven successful in continuous operation (Figure 8).

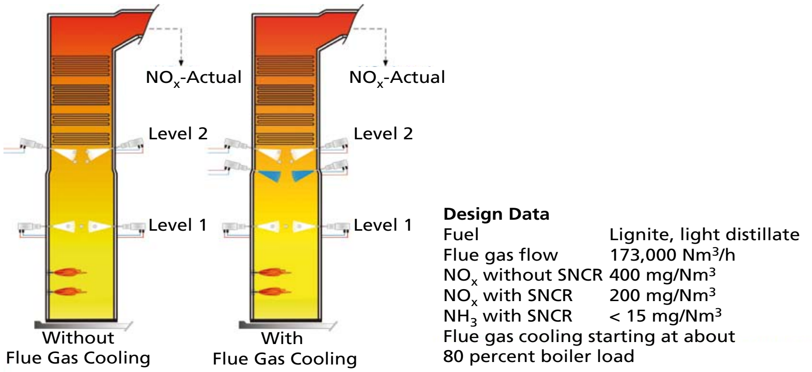

Figure 8: Coal-fired boiler with and without flue gas cooling

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 is not changed, but the disadvantage is that temperature imbalances can lead to a higher NH_3 slip, because the cooling also takes place in areas where the temperatures are within the right range and therefore, flue gases would be too cold for the NO_x reduction. The effect would be an increase of NH_3 slip, a waste of cooling water and lower efficiency.

Preferably, this method should be applied only in combustion plants that are not constantly operated in temperature ranges which require an additional cooling of the flue gases or in plants with homogenous temperature profiles. By switching on or off the cooling water an additional injection level can be avoided in many cases.

4. Most recent developments of NO_x reduction with SNCR

4.1. Selective cooling of flue gases

Selective Cooling is a method which takes us one step further. It also requires an additional injection level for cooling water beneath the top injection level, but it improves the efficiency of this additional level. The major difference is that Selective Cooling reacts to temperature imbalances in a way that cooling water is injected only in those areas which are too hot.

Individual lances or groups of lances are activated depending on the temperature profile generated by a suitable temperature measurement system (Fiure 9).

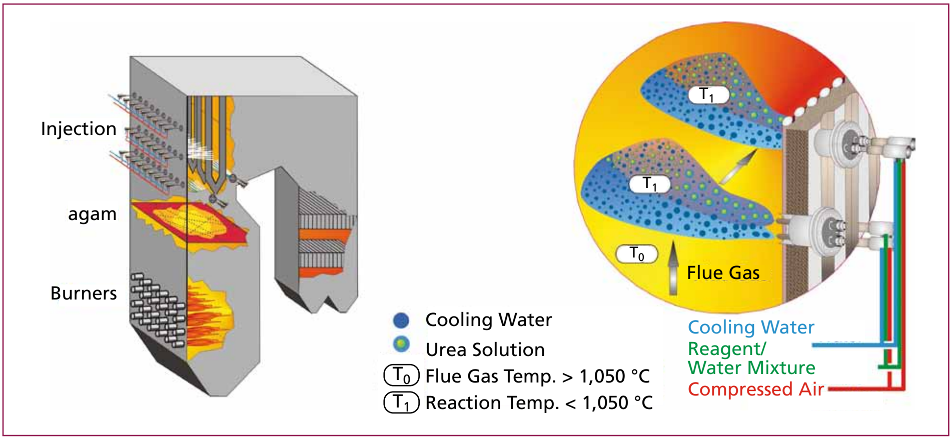

Figure 9: Selective flue gas cooling for coal-fired boilers

Figure 10 shows the results of the Selective Cooling in a coal-fired boiler in the Czech Republic. With additional cooling water alone, the NO_x reduction of the SNCR could be increased by an additional 120 mg/Nm³ to a level of < 160 mg/Nm³.

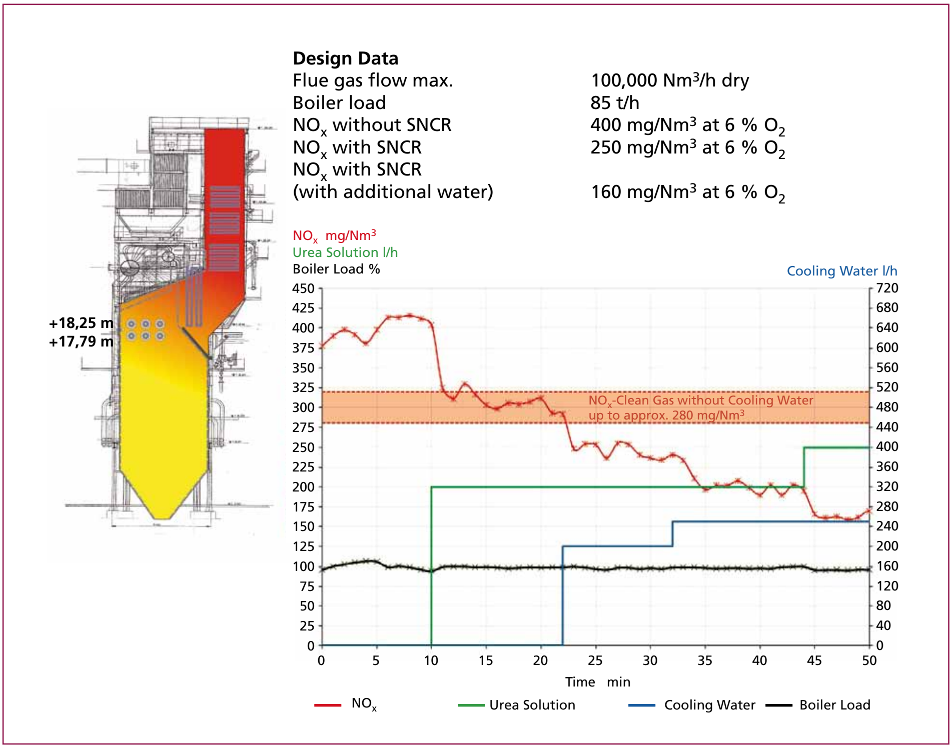

Figure 10: Selective cooling – Retrofitting of an SNCR plant operated with urea solution

4.2. Adaptive flue gas cooling

Injecting of water offers the great benefit that extensive and costly modifications of the boiler can be avoided when the flue gases are cooled down before entering the heat exchangers. The major disadvantage, however, is that depending on the operating hours at high boiler loads in which water cooling is necessary, the efficiency of the boiler is affected because of the energy needed to evaporate the water in the flue gas. *Selective Cooling* is already a big step forward to improve the performance of SNCR by cooling down the flue gases.

However, a better solution is to control the amount of water more precisely in order to further decrease the consumption of cooling water.

To realize this objective a temperature measurement system which generates a temperature profile has to be installed above the upper injection level of the cross-section of the furnace (Figure 11).

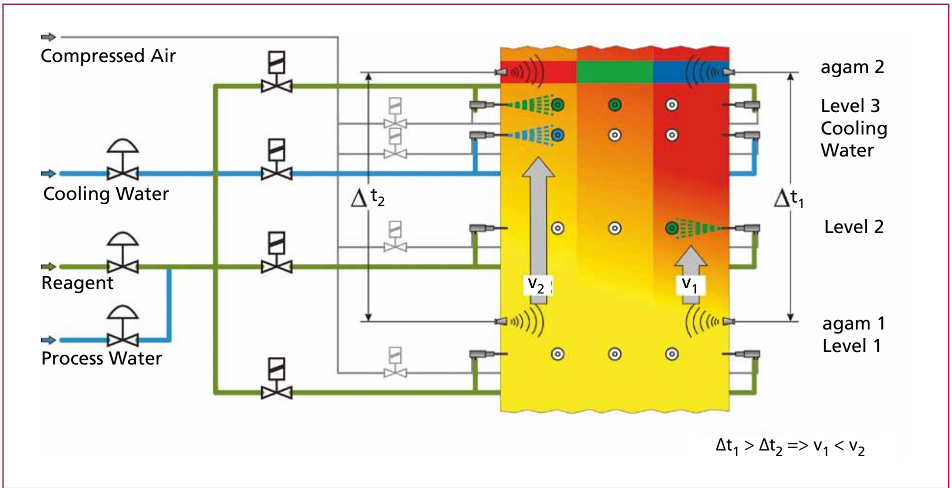

Figure 11: Principle of adaptive flue gas cooling

The temperatures are constantly being measured online and average flue gas temperatures are calculated in defined sections which are assigned to single injectors or groups of injectors.

- Without injection of reagent,
- With injection of reagent only,
- With injection of reagent and cooling water simultaneously.

At the lowest level, injection of cooling water is generally not needed, since the injectors will be switched to higher levels as the flue gas temperatures increase with the load.

With the described concept the temperatures and the influence of the injected liquids, i.e. reagent/water-mixture and cooling water, can be measured. Based on the various temperatures the flow of cooling water can be adapted as needed to maintain the optimum temperatures within the injection level in order to obtain efficient NO_x reduction and low ammonia slip. Furthermore, the activation of the lances for reagent can be determined more precisely when temperatures are measured in two levels.

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

Defining flue gas velocity

It is often neglected that apart from the flue gas temperatures, the flue gas velocities at different injection positions, are of equal importance for the efficiency of the SNCR process. Since the NOx to be reduced is the product of

$$NO_x \text{ concentration } [mg/Nm^3] \bullet \text{ velocity } [m/h] \qquad (1)$$

the probability is high, that in some areas where the flue gas velocities are low, too much reagent is injected in areas with similar NO_x concentration causing higher ammonia slip since the reagents do not find enough partners for the chemical reaction. To avoid this, the flow of reagent should be reduced or stopped to decrease the consumption of reagent and minimize ammonia slip.

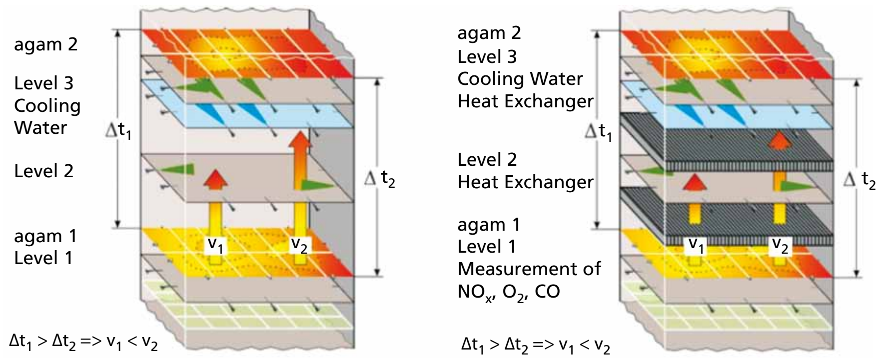

Figure 12: Adaptive flue gas cooling – Extrapolating flue gas velocities from differences in temperature

With this arrangement of the temperature measurement systems in two levels (Figure 12), the temperatures in the levels and sectors can be compared and the temperature gradient between the levels can be defined more correctly than with traditional methods.

Since hot flue gases have a higher natural draught and slower flue gases are cooled down more at the boiler walls and heat exchangers, higher temperature differences indicate a slower flue gas velocity compared to areas with smaller temperature differences.

This information is the basis to control, respectively adjust the flow of reagent to the corresponding injectors or groups of injectors with the objective to optimize the NO_x reduction and to minimize the ammonia slip.

If measuring equipment were used which provides data of other components like NO_x, CO, O_2, etc. in addition to the temperatures, these data could be incorporated into the control of the SNCR as well as into a further optimized distribution of the reagent across the furnace for better performance of the SNCR.

5. Summary and outlook

In smaller combustion plants like those that burn waste or biomass, the SNCR process has been well established and accepted as Best Available Technology (BAT) since many years. In the meantime, the operating experiences in large combustion plants with a capacity of > 200 MW_{el} have shown that the NO_x levels required under the new EU legislation from 2016 on can reliably be reached.

Recent techniques like the changing of individual lances, the TWIN-NO_x process, the Selective Cooling and Adaptive Cooling of flue gases in combination with primary measures have produced results which indicate further potential for improvements. Currently, there is an increasing demand for plants that have boilers with an output of 300 to 500 MW_{el} and emission levels of < 150 mg/Nm^3 and NH_3 slip < 5mg/Nm^3.

6. Literature

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