Title:

NO_x Control in Large Scale Thermal Power Plants with a Combination of Advanced Combustion Optimization with Online Three-Dimensional Temperature Analysis and Self-Tuning SNCR

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Summary

In STEAG Fenne's 576 t/h steam generator the combustion is optimized by an advanced process controller. This system improves the air-/fuel-ratio and thereby increases the efficiency, based on the analysis of

- conventional process data
- vibration data from mills and pulverized fuel pipes
- real-time flame properties

Flame characteristics and vibration signals to analyze coal flow distribution and grinding degree are correlated with conventional process data and are fed into self-tuning neural networks (NMPC nonlinear model predictive control).
Continuous increases in the boiler efficiency by 0.4 percent and a primary NO_x reduction by approx. 20 mg/Nm³ are the result.

Additionally the SNCR (SNCR hardware has been installed by a standard supplier) is controlled to the optimum. To cope with the challenge of the strong temperature dependency of the SNCR, a new online three-dimensional temperature analysis "Online-CFD" was developed and implemented. The Online-CFD provides permanent knowledge about the current temperature distribution in the relevant boiler part; this happens in dependency of the current fuel, mill state and load as well as boiler state and load. The results are used as a basis for the temperature-driven SNCR control. The SNCR control

- achieves an optimal activation of the single SNCR nozzle by using a valid Online-CFD and adapts itself to changing process situations like e. g. changes in coal qualities, mill wear, wall slagging, soot blowing etc.
- ensures compliance with the limit values for NO_x and ammonia slip in all load cases (10 percent - 100 percent).

The combination of primary NO_x reduction with advanced combustion optimization plus Online-CFD as a basis for a temperature-controlled self-tuning SNCR thus results in

- burner-side primary NO_x reduction by 20 mg/Nm^3
- an increase in the boiler efficiency by 0.4 percent
- adaptive and automatic SNCR nozzle activation in suitable flue gas temperature ranges
- safe NO_x limit and ammonia slip compliance for all load cases

1. Introduction

After optimizing the combustion successfully at the STEAG MKV Fenne, control software from STEAG Powitec GmbH as well controls the SNCR hardware, which was installed by a standard supplier. This new temperature-driven SNCR control is based on Online-CFD and was developed in close cooperation with the plant management of STEAG Power Saar GmbH, Thermal Power Plant Fenne.

1.1. The MKV Völklingen (STEAG Power Saar GmbH)

Fenne power plant is a location of STEAG Power Saar GmbH (formerly Evonik New Energies GmbH) in Völklingen, Germany. Fenne mainly consists of the motor-operated combined heat and power plant, the combined heat and power plant Völklingen (HKV) and the model power plant Völklingen (MKV). The installed gross capacity amounts to 505 MW and the district heating capacity is 615 MW.
The MKV has an installed gross capacity of 195 MW and a district heating capacity of 150 MW. The steam generator is a forced-flow boiler having intermediate superheating with two drafts and a throughput of 576 t/h. The burner system consists of eight low-NO_x DS burners in a staggered, opposed arrangement at four elevations. Air staging is conducted by secondary air 1 and 2, shell air at the boiler walls and over-fire air as burn-out air. To achieve the NO_x limit value, a lambda value of 0.8 is set at the burners, and the overall air index is increased with shell air and over-fire air to 1.25 (values at full load).

Especially the wide operational load range of 30 percent to 100 percent and the many load changes of eight per day with a load change of more than 10 percent make the NO_x level control challenging.

The primary task was to optimize the combustion to reduce the overall oxygen, leading to a NO_x reduction.

1.2. Combustion Optimization

In 2005 STEAG installed the combustion optimizer PiT Navigator in the MKV. PiT stands for "Powitec Intelligent Technologies", and the PiT Navigator is STEAG Powitec's core solution for thermal power plants. The PiT Navigator is an advanced auto-optimizer for the permanent optimization of the air/fuel ratio and air/fuel distribution. High-speed cameras observe the combustion chamber and extract significant features of the ignition-, combustion- and burnout-behavior, temperatures, position and emissions with a computerized pattern recognition process. Vibration sensors capture mill vibrations giving early information about milling degree and coal quality. Process data from the PCS are permanently correlated with optical and vibration information through a software based on neural networks. These neural networks are modeled in self-learning adaptive software based on process data of a variety of operating points. This allows them to adapt to changing process situations. Expert knowledge is integrated and the software improves this knowledge in a self-learning and self-optimizing mode.

The PiT Navigator's performance was discussed in VGB PowerTech from December 2007 in the article "Performance Contracting for a Combustion Optimizer, based on Neural Networks in a Coal-Fired Power Plant". The main results are:

- A reduction of combustion air by 4.8 percent, leading to an increased boiler efficiency of 0.39 percent.
- For the MKV, this represents 1,324 t of coal/a and 2,168 t of CO_2/a and – due to the reduced fan usage – a saving of electrical energy consumption of about 1,989 MWh/a.
- In spite of the total air reduction, the boiler wall atmosphere is improved and less CO-induced corrosion is observed.
- The unburned carbon in ash is reduced by 5%rel.

- Less slagging is experienced as well.

The optimized combustion results from an optimization of the local air/fuel ratio at each burner and is also due to the reduction of the excess air by approx. 1 percent O_2. One percent O_2 reduction equals to about 15-20 mg/m³ NO_x.

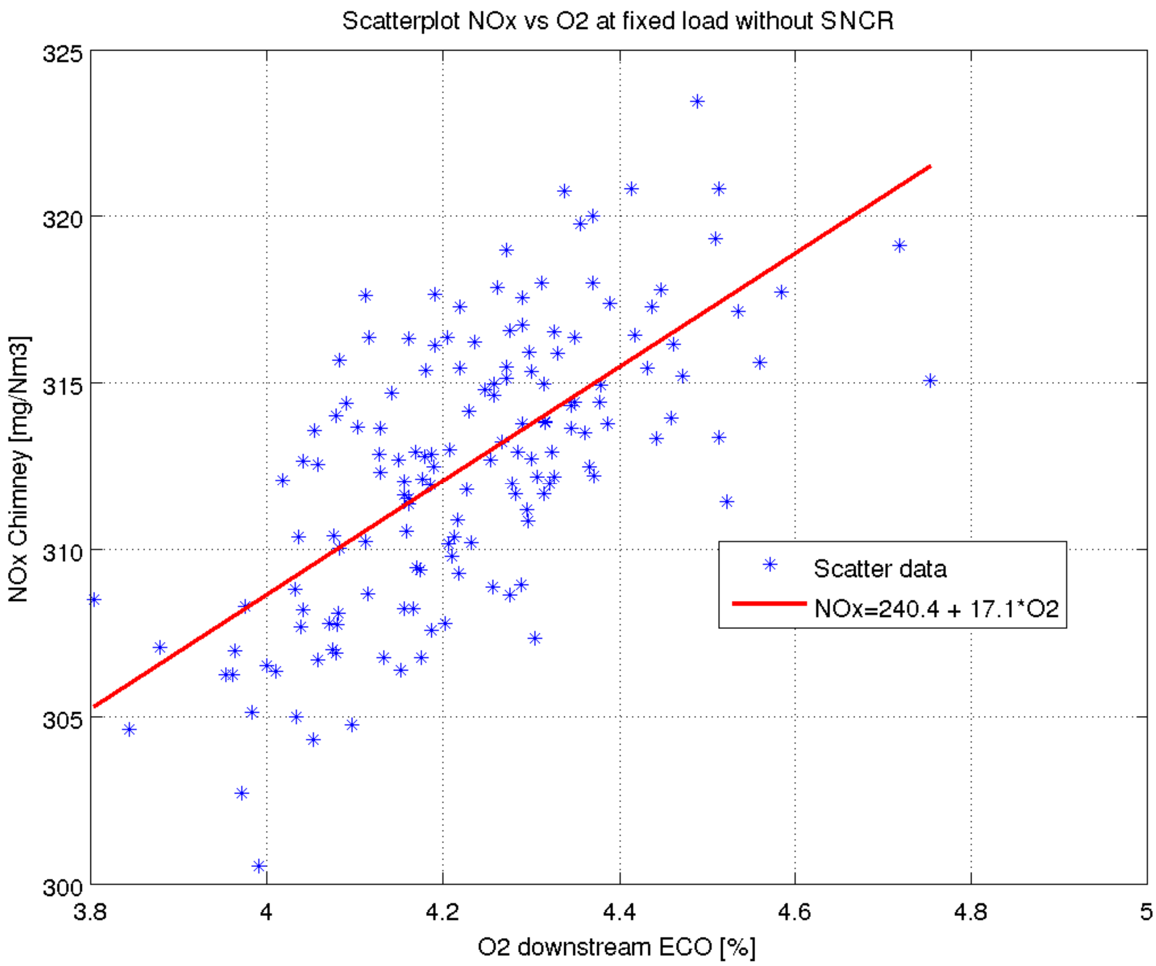

Fig. 1: NO_x as a function of O_2 at constant load, same coal quality, no SNCR and no soot blower operation. The optimizer reduces the O_2 in average by 1 percent, equal to a primary NO_x reduction of approx. 20 mg/Nm³.

After the primary NO_x reduction through low-NO_x burners and the combustion optimizer, a secondary NO_x reduction still is necessary. MKV had to decide between investing in a SNCR or a SCR.

2. SNCR Versus SCR in Large Scale Boilers

Before deciding about installing a SNCR or SCR, MKV analyzed the general advantages and drawbacks:

SNCR advantages:

- Less space required
- Lower investments
- No costs for catalyst regeneration
- No flue gas pressure loss
- Easy commissioning

SNCR drawbacks:

- Consumption of ammonia could be higher than with an SCR
- Ammonia slip could be problematic
- Advanced control system required because the knowledge about or control of the local temperature is challenging

Especially at the MKV Fenne the very large economizer leads to too low temperature and too limited space for a high-dust SCR. Additionally the flue gas desulphurization is installed in the cooling tower which has the consequence that there is not enough space for low-dust SCR.

The result of the analysis was that the SNCR was chosen as the best choice.

2.1. SNCR

The SNCR hardware was supplied by a standard supplier and is made up of a storage tank, mixing and measurement modules, distribution modules, and 60 lances on five elevations. Each lance is individually controllable and the ammonia-water flow is controlled in groups.
The determination of the positions was carried out by this standard supplier on the basis of on-site measurements and off-line modeling.

The SNCR's efficiency strongly depends on the flue gas temperature in front of the available lance and level (more in the next chapter). In everyday operation it became obvious that there is significant room for improvement regarding the amount and position of the lances. The fifth level for example is almost not used at all. This is why STEAG Powitec suggests for future installations to decide the lance position on the basis of an Online-CFD and after observation of different load cases and coal blends.

2.2. *Temperature Dependency of the SNCR*

It is well known that the selective non-catalytic reduction strongly depends on the temperature of the flue gas (see Fig. 2). Injections of ammonia water into too cold regions would inhibit the reaction, whereas injections to areas which are too hot would burn the ammonia and produce even higher NO_x emissions.

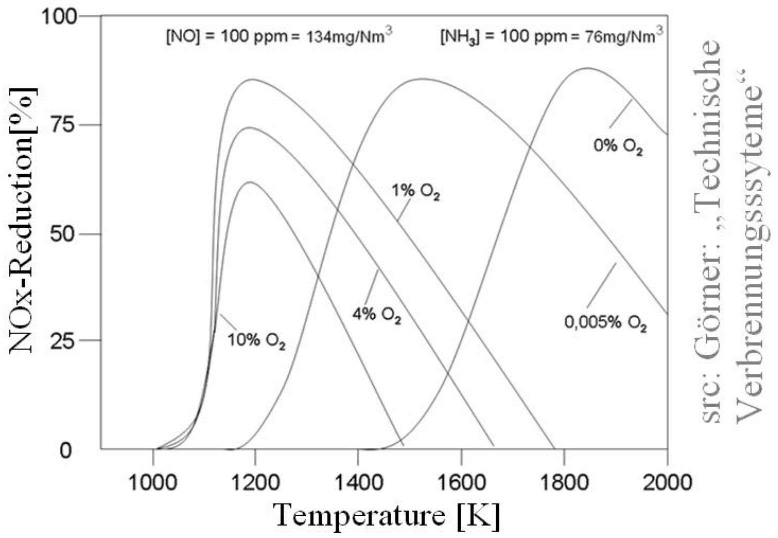

Fig. 2: NO_x reduction depending on flue gas temperature and O2.

Usually, the three-dimensional shape of the suitable temperature window inside a furnace looks like an inner open cone (see Fig. 3). Thus the challenge is to find those SNCR nozzles which inject the absorbent into the right temperature window.

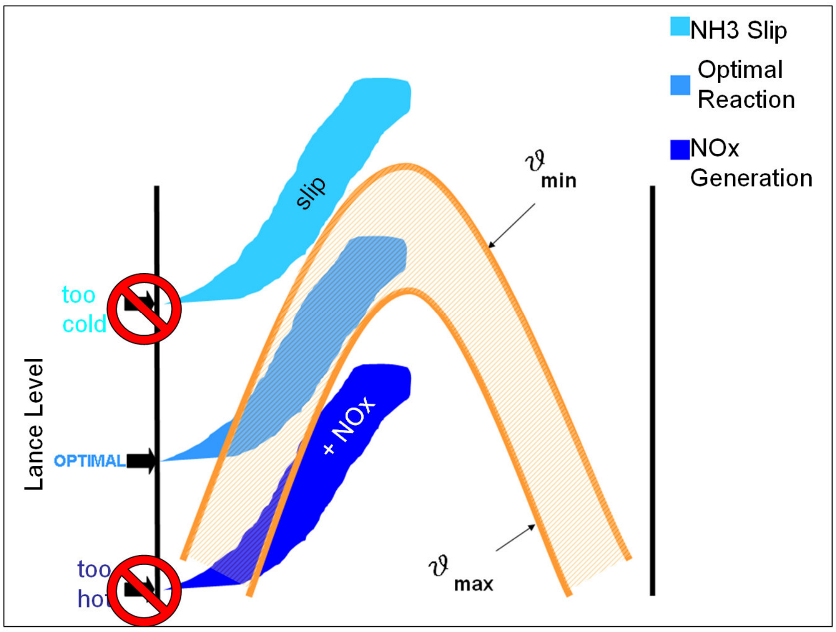

Fig. 3: The right temperature window is in an inner open cone.

This search for the right SNCR nozzles is especially challenging at changing loads and coal qualities because the suitable temperature window moves significantly in space.

To find the current location of the suitable temperature window, STEAG Powitec introduced the online modeling of the three-dimensional temperature distribution inside the furnace.

3. Modeling of the Temperature Distribution – Online-CFD

Together with STEAG Powitec, STEAG Power Plant Fenne has developed the online modeling of the three-dimensional temperature distribution inside the furnace. For this, a simplified version of traditional CFD approaches is used. The furnace volume is split into numerous cubicles, and the Reynolds-averaged Navier-Stokes (RANS) equations are solved. Since only relatively few cubicles are used, it becomes possible to solve these equations very fast in real time. Due to this online operation of the CFD model, it is possible to feed the CFD solver online with all available measurements of the process in order to provide real time constraints. Thus, the result of the CFD simulation always follows the current process situation within seconds.
Furthermore, it is necessary to model the individual burner flames with their thermal and dynamic behavior depending on their coal and air flows, and the current coal heating value. For this purpose, information from additional STEAG Powitec furnace cameras is used to support the CFD model.

The combustion room is modeled by:

- Separation of the relevant area in volume elements. At MKV Fenne (boiler dimensions: 10 m (length) x 10 m (width) x 40 m (height)) volume elements with a border length of 1m are used. This results in 4,000 volume elements.
- For each volume element the following flue gas parameters are modeled:
  - Temperature
  - Mass
  - Density
  - Speed in x, y and z-direction
- Modeling of over-fire air and superheater
- Balancing of the spray picture of the NH_4OH and of the droplet spectrum
- Consideration of soot blowing
- Modeling of wall slagging

As mentioned before, this model is calibrated online by integrating existing values from the process control system, i.e. measurements of thermo elements or steam parameters as well as the STEAG Powitec sensors (digital optical flame analysis) as constraints for the CFD.
Thus, a new three-dimensional distribution of temperatures is calculated every 15 seconds, and the respective visualization delivers fascinating insights to the load-depending changes in the first draft.

3.1. Validation

To validate the modeling, STEAG Power Plant Fenne carried out extensive measurement campaigns to verify the temperatures shown by the Online-CFD. As part of this study, gas-extraction pyrometer measurements were carried out on two elevations with different measurement depths ranging from 0.5 meters to 4.5 meters at various loads (25 %, 72 %, 100 %).

The temperature differences between the Online-CFD model and the gas-extraction pyrometer measurements were only small as Fig. 4 indicates.

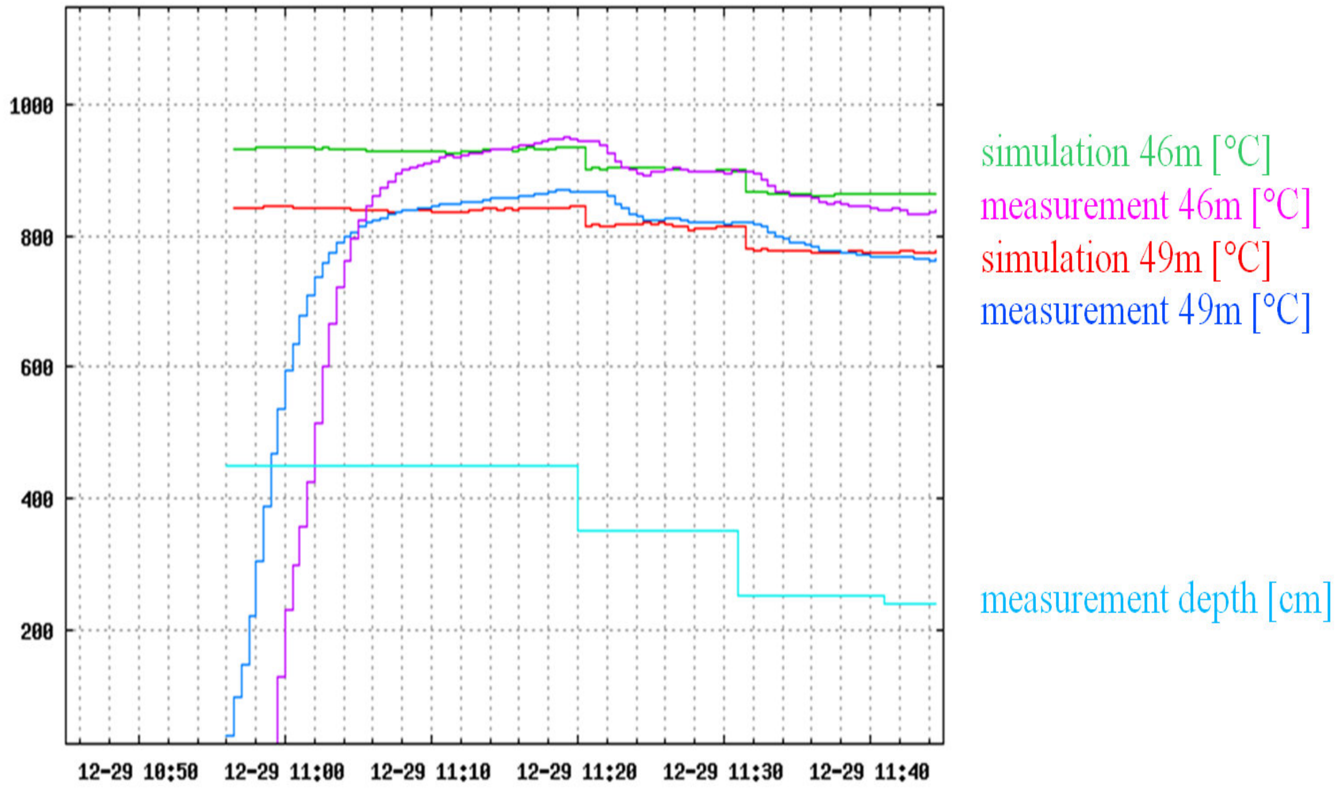

Fig. 4: Gas-extraction pyrometer (measurement) compared to Powitec Online-CFD (simulation) at different depths and elevations

In conclusion, the power plant and operation management stated that the calculations of the Online-CFD reflect the real temperature distribution inside the furnace and that it seems suitable for selecting the locations of SNCR nozzles.

4. Control of the SNCR

As a secondary activity for NO_x reduction, the SNCR comes into the picture. But as discussed before, the temperature dependency of the chemical reaction needs detailed information about the current temperature distribution at the lance elevations. Additionally, the flue gas amount which can be reached by the single SNCR lance (spray picture) has to be calculated. At MKV the temperature distribution throughout the first draft, if necessary up to the boiler end, is calculated by STEAG Powitec every 15 seconds. Current measurements of the process variables are imposed as well every 15 seconds (online calibration). Together with a calculation of the achievable flue gas volume in the appropriate temperature window, this enables for an activation of the right SNCR nozzle.

Together with STEAG Powitec, STEAG Power Plant Fenne developed the SNCR control model. This model follows limits, targets and priorities for NO_x, slip and ammonia consumption. The model permanently calculates

- the NO_x setpoint characteristic curve (depending on load, load transient and slip) as well as
- amount of active lances, position of active lances and current mixture ratio.

In this calculation the model considers the

- actual value of NO_x,
- lab value slip in fly ash,
- current slagging and fouling status,
- boiler geometry,
- actual coal values (grinding degree and amount per burner),
- actual burn-out models and
- spray distribution models.

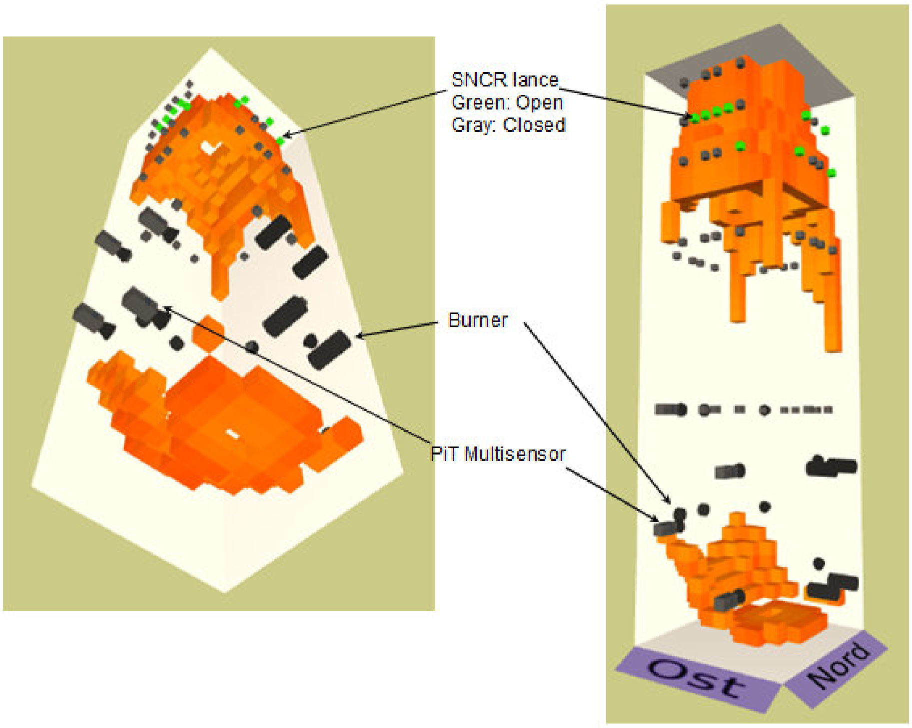

Fig. 5 shows the boiler model together with temperature boxes in a temperature window of 900 to 1,000°C. Additionally the SNCR lances, burners and STEAG Powitec optical sensors (PiT Multisensor) are indicated. In the left picture it is very obvious that the appropriate temperature has the form of a dome.

The continuous changes of plant load show fascinating insights into the temperature distribution over time and the adapted SNCR nozzle selection:

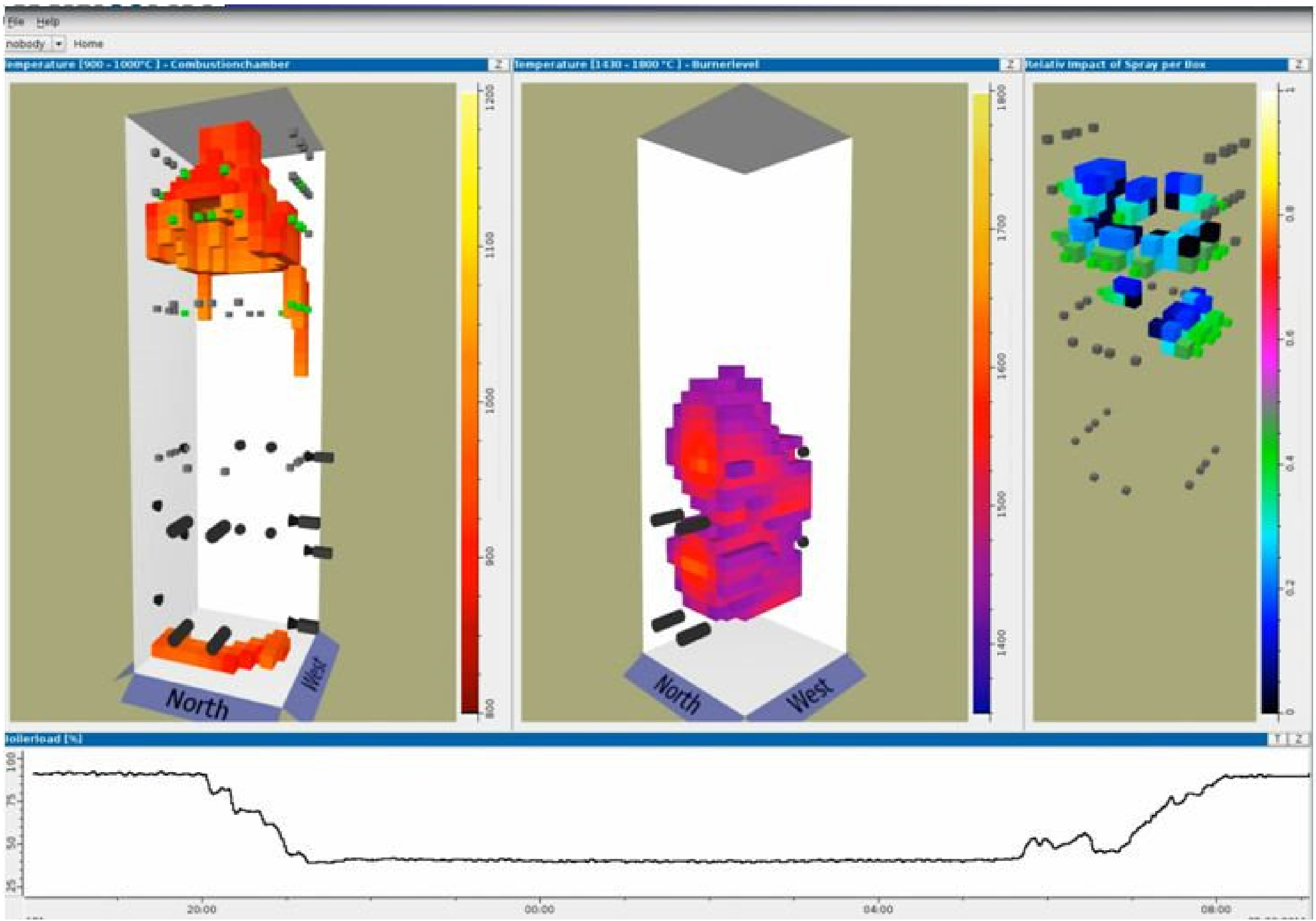

Fig. 6: Screenshot of the Online-CFD and the SNCR control. The left picture shows locations of temperatures between 900 to 1,000°C in the combustion chamber (orange boxes) and the activated lances (small green boxes). The picture in the middle shows the locations of temperatures between 1,430 and 1,800°C. The right picture shows the locations of relative (0 to 100 percent) impact of ammonia spray per 1m³ box (cyan and blue boxes)
The lower picture shows the figure of the boiler load over 24 hours.
The load-depending changes in temperature distribution and spray amount over the time can be seen in a video: http://www.powitec.de/Videos/PiT_OnlineCFD_FlueGas_Flame_Spray.avi

5. Results, SNCR Control

The STEAG Powitec SNCR control (Sept. 2010 to today)

- achieves an optimal activation of the single SNCR nozzle by using a valid Online-CFD
- adapts itself to changing process situations like changes in coal qualities, coal mill usage, wall slagging, soot blowing etc.
- keeps the setpoint values for NO_x and ammonia slip in continuous operation for all load cases (30-100 percent).

During further tests at full load it was examined if it could be possible to improve the SNCR manually. During periods with stable load, the SNCR control was tried to be optimized manually i.e. by manual shift towards lower or higher SNCR nozzles. The resulting NO_x levels and the ammonia slip respectively clearly indicate that the Online-CFD finds the optimal injection locations at full load.
The same tests were carried out at stable part load and again; either the NO_x or ammonia slip level increased when a manual control was tried out.

6. Summary

The Online-CFD as a new approach for temperature-controlled SNCR in large scale steam generators can be summarized as follows:

6.1. STEAG Powitec SNCR Control Approach

The STEAG Powitec SNCR control approach has the following steps:

- Burner-side primary NO_x reduction on top of low-NO_x burners by optimization of air distribution and reduction of excess air
- 3D Online-CFD of flue gas temperatures
- Modeling of mass, temperature and speed of flue gas by solving RANS equations (Reynolds-averaged Navier-Stokes equations)
- Online calibration using plant measurements every 15s
- Automatic nozzle activation following Online-CFD temperatures

6.2. Results

The following results were achieved:

- Burner-side primary NO_x-reduction by about 15 to 20 mg/Nm^3 and increase in the boiler efficiency
- Automatic SNCR nozzle activation in suitable flue gas temperature ranges
- Safe NO_x setpoint compliance for all load cases
- Safe ammonia slip setpoint compliance for all load cases

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