Improved SNCR Performance by Means of Innovative Control Concepts

Wolfgang Schüttenhelm and Philip Reynolds

Today, SNCR (Selective Non Catalytic Reduction) Technology is a well proven technology to meet even very challenging NO_x reduction requirements. Continuous developments of the reduction agent injection system, online temperature measurement systems as well as improved automation concepts have increased the SNCR NO_x control efficiency as well as its flexibility and reliability. Among others, ERC's sophisticated dual injection process has been developed combining the company's high performance injection technology with simultaneous injection at two different SNCR levels and individually switching of single lances [4]. Compliance with the new emission limits for NO_x and NH_3 of the German 17. BImSchV for waste-to-energy plants could already be demonstrated.

In detail, daily average limits of 150 mg/Nm^3 NO_x and 10 mg/Nm^3 NH_3 are to be met for new and existing Waste-to-Energy units of more than > 50 MW thermal capacity from 01.01.2019 same as the new annual NO_x average limit value of 100 mg/Nm^3 for new units. All of these limits are based on the actual O_2 content if it is below 11 Vol.% dry.

Besides, computer based modelling provides new and advanced tools to further improve SNCR performance respectively reduce the cost of the reduction agent. For this purpose, the company ERC developed Opti-Link which is an online-balancing based calculation tool improving SNCR control efficiency and providing additional features such as plausibility checks of measured plant data and more [3].

This paper describes the most recent developments of the tool as well as new modules which can be integrated to model the grate firing system as well as the SNCR injection performance. The first results show a very promising additional performance potential which is based on the integration of additional information about the waste input, firing system and SNCR operation.

1. Challenges for the operator of Waste-to-Energy plants

Operation of a Waste-to-Energy plant has to consider multiple requirements which might even contradict to one another. Of course, it is mandatory to meet the legal emission limits. Thus, it might be useful to lower the temperature of the furnace by reducing the load in order to operate the SNCR at its optimum temperature. A load reduction will also contribute to a longer boiler running time. On the other hand less waste would be incinerated and less electricity and / or district heat would be produced. Lower legal emission limits are adding more focus to such complex topics for the operator who should meet all of the following targets at the same time:

- High throughput of waste – avoid part load operation
- Emissions below legal requirements
- Long boiler running time
- High energy efficiency
- Low cost of operational utilities and reduction agents
- Low cost of maintenance and repairs

However, conflicting scenarios are more probable as the operator always acts after having recognized the parameters out of a huge set of many different operational measurements being indicated on the screens of the process control system. Depending on the experience of the operator he / she will take the conclusions and correct operational parameters accordingly. There is no explanation how the measured values are interacting and which dependencies are existing among a very comprehensive set of measured values. However, such dependencies can be calculated by means of online balancing and simulation of scenarios recommending actions which will transfer the plant to the best possible operational status under the current conditions.

Since the performance of the SNCR is strongly influenced by means of the upstream firing system it is playing an important role while optimizing the overall operation of the unit [3]. There always are two ways to improve SNCR performance: first of all, the reduction agent has to be injected exactly into a furnace section showing the required SNCR temperature and having a high baseline NO_x concentration. Secondly, improved SNCR conditions can be provided by means of adapting the parameters of the firing system e. g. by means of changing the combustion air amount and its distribution. As mentioned before, such requested adaption of settings might conflict with other targets of the operator.

Process-side mechanical extensions and improvements of the SNCR system provide the required base to act more flexible and achieve lower emission values. Among others, additional injection levels are required for SNCR operation for a large temperature window being caused by vast changing waste quality and heating value in order to warrant full load operation over the complete planned boiler running time. Additionally, lower consumption rates of the reduction agent may be achievable. Samples of result of retrofits with such measures are presented in [4].

Even after having installed all process and mechanical measures some conflicts will still remain. Since the fuel never has a homogenous composition and constant heating value, very fast and extreme deviations of the firing conditions inside the furnace are occurring which have to be mastered by means of fast control actions. Otherwise, the reduction agent might be overdosed resulting in increased ammonia slip or lower $DeNO_x$ performance.

Therefore, an additional control system on top of the today's plant standard is required that collects and analyses the data, estimates additional process variables and provides recommendations to the operators by proposing settings for the respective parameters. The proposed settings are useful on the one hand to improve SNCR performance and on the other hand to optimise the total plant. The algorithms of such a system have also to evaluate the different possible measures. ERC as well-established supplier of $DeNO_x$ solutions has already started to design such a novel and integrated approach which is described in the following chapter in detail. For the sake of simplification it is named *platform*.

2. Platform and tools for monitoring and control

Since the new system shall be open to operate multiple units or even multiple plants of a plant owner and as new features and extensions have to be added easily the platform has to follow a suitable general concept. Among others, Opti-Link being the company's raw gas concentration prediction tool will be integrated into the overall platform as one of the apps of the new analysis and recommendation system. The tool is described in detail in Chapter 3.

2.1. Platform

While developing the concept of the overall platform huge focus has been applied to interfaces, coding techniques for data protection and storage of data balancing. The following criteria have to be met:

a. Encoding following the highest safety standards
b. Cloud feature in order to warrant scalability and provide easy updates in future
c. Stand-alone operation without internet connection to operate on local computers
d. Central data base
e. Simple interface to integrate future applications
f. Visualisation of collected data by means of a dashboard

Therefore, this new platform offers the potential to incorporate other applications which might be developed by separate sources. Thus, doubling of functions is avoided and future extensions of the system are much easier to execute. The principle structure is shown in Figure 1. At the left side the process control systems of different units/pants are listed in yellow boxes. The platform management system is also indicated in yellow in the centre of the graph, the database is shown in blue while all the applications are shown as green boxes at the right side.

The open structure of the platform is comparable to a mobile telephone and its operation system. Some applications are already installed and other applications from other vendors can be installed later on.

2.2. Platform-internal monitoring

Data monitoring is executed within the platform. All input data and results are collected in a central data base. A central data exchange interface is used to allow the access of the process control system and all applications to the central data base. One of the most important applications of the platform is the online balancing tool. Its results are also stored within the central data base. Within the online balancing tool the balancing areas have to be defined which are covering the different sections of the plant such as boiler or flue gas cleaning. Therefore, a lot of information (e. g. heating value or amount of false air) is already indicated online to the plant operator in real time as soon as the online balancing tool is in operation [1].

The common interfaces are system open. Thus, it is possible that third-party application programmers have many options selecting the programming language of their applications as long as the definitions of the central data interface are followed. Possible programming languages are e. g. C++, Visual Basic, Java or Matlab.

2.3. IT-security and scalability

The safety of the waste-to-energy facility is of highest importance. This safety aspect does not only affect the process and plant technology but also comprises the IT security which is essential.

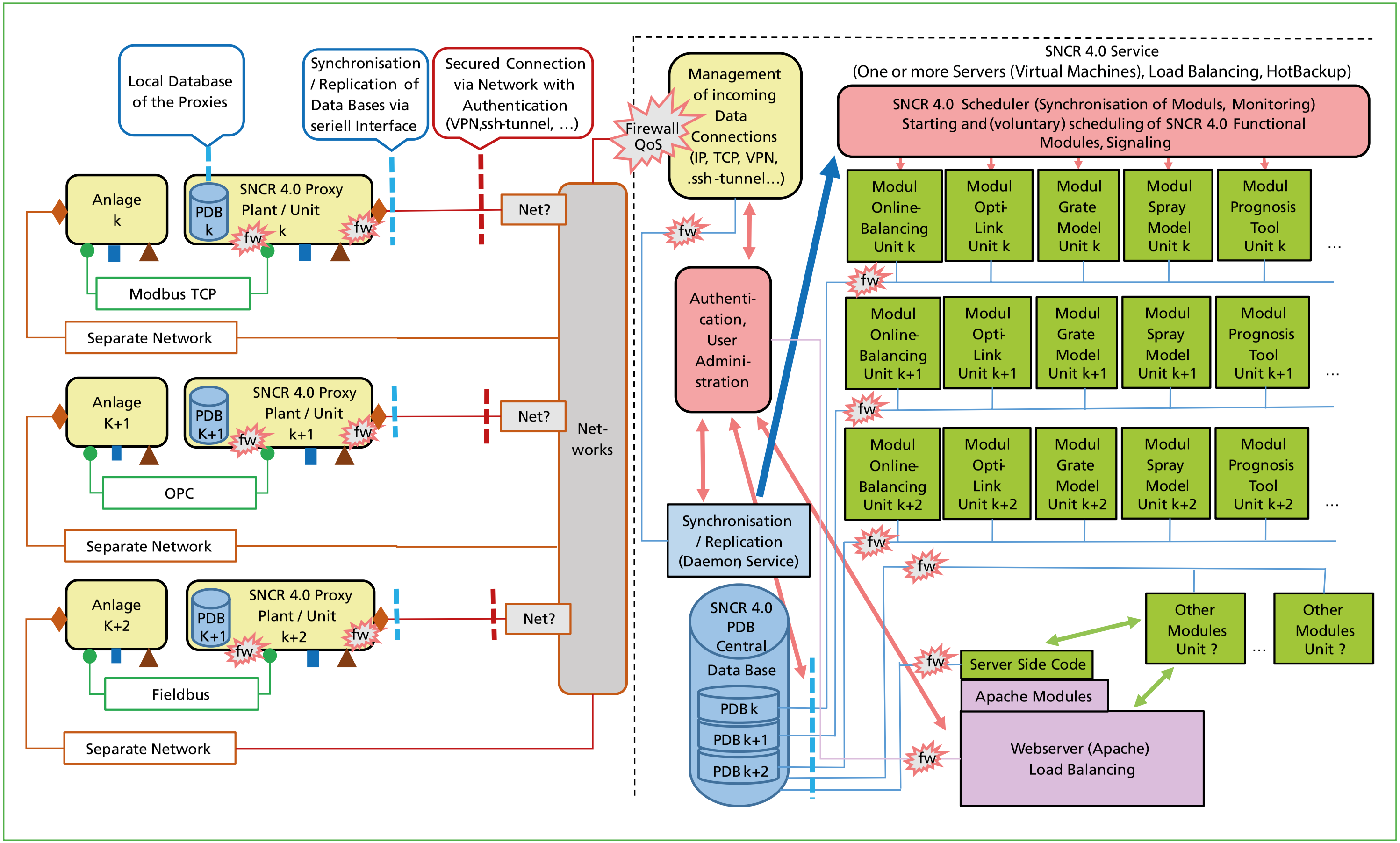

Figure 1: Structure of the platform

Monitoring is based on the collection and analysis of data. The acceptance of the monitoring tool by the staff strongly depends on the security of the data. Therefore, the platform design offers maximum transparency for the operator. Additionally, it is equipped with strong encoding technology.

Scalability is ensured by integrating data exchange by means of a cloud. Using a cloud for data exchange is also a protection against data loss. However, it is also possible to run the system locally without connection to the internet and cloud. This feature is very important because many plant operators are very critical towards the use of cloud solutions due to IT security reasons.

2.4. Applications (Apps) for firing system and SNCR optimisation

An overview about the current applications of the platform is provided within the following chapters. These are the following *apps*:

- Denitrification App – Opti-Link
- Grate Model App – NO_x raw gas calculation for different grate zones
- Spray Model App – SNCR performance modelling

The Grate Model App as well as the Spray Model App are the most recent developments enabling an integrated approach to design and operate an SNCR according to the applied waste input parameters and taking into account different grate zones resulting in different NO_x raw gas concentration over the combustion chamber cross section.

3. App denitrification – Opti-Link

Some applications for the platform are already available. They were presented already before in detail [3] [4]. These existing products were adapted and optimised to operate as an App of the new platform. The main features and advantages of Opti-Link are as follows:

- Estimation of the average raw gas NO_x concentration upstream of the $DeNO_x$ process.
- Plausibility check of measured values
- Making available non-measurable parameters such as the heating value in real time
- Estimation of the waste composition
- Online control of the SNCR

The improvement of NO_x control by means of application of the tool results in minimizing of the effect of the delay time between the SNCR reduction agent injection and the NO_x measurement controlling the emission value. Measuring delays of several minutes (up to 5 minutes and more) are typical for such plants. Due to the tool it is possible to significantly shorten this delay time and, consequently, either operate the plant with lower average NO_x emissions and / or reduce the reduction agent amount. However, those calculations are based on global calculations. Moreover, no recommendations of actions are proposed to the operators. Of course, the online calculation of an average NO_x raw gas value already presents an initial breakthrough for a better SNCR control efficiency.

3.1. NO_x-raw gas concentration prediction

The quality of the SNCR control depends on the type of control parameters as well as on the availability of measured values and on their timing. Older generations of SNCR systems with moderate or low performance just used a load signal such as the amount of steam production or the furnace roof temperature. Such a control concept is entirely unsuitable to control SNCR systems which have to meet the new lower emission standards.

Ideally, the NO_x raw gas value should be available in order to adjust the quantity of the reduction agent. Obviously, it cannot be measured prior to the SNCR. Therefore, the long delay time between reduction agent injection of the SNCR process to the clean gas measurement at the stack apparently became disadvantageous when tightening the limit values, see also Figure 2.

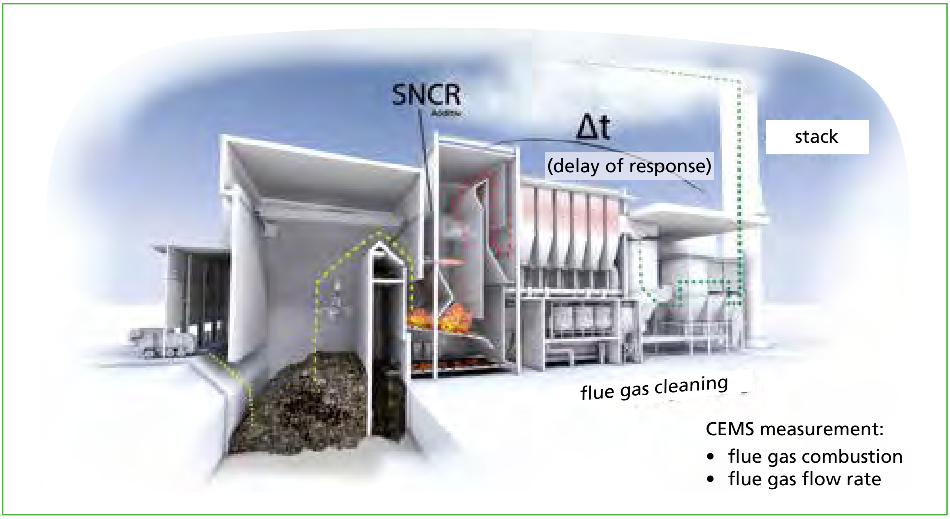

Figure 2: Delay time between SNCR and NO_x clean gas measured at the stack

This problem can be reduced by installing NO_x and NH_3 analysers at the boiler outlet. Of course, such measurements including calibration and maintenance are also a cost factor.

If such measurements are not available or if the delay time is still too high to solve a challenging NO_x reduction problem Opti-Link provides a new solution [3]. The system calculates the NO_x raw gas value downstream of the firing system by means of online balancing. Measured energy and material flows and analysis of a waste composition database can be used for the estimation of the NO_x raw gas value in order to faster adjust the quantity of the required reduction agent. If the SNCR is switched off during a test, the calculated and measured value for NO_x can be directly compared. Figure 3 shows both values in comparison.

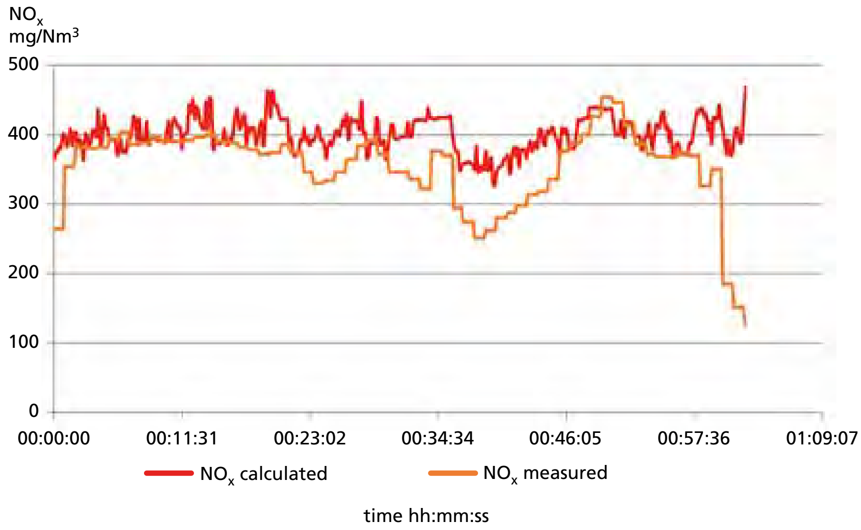

Figure 3: NO_x-raw gas value, measured and calculated by means of Opti-Link

Furthermore, the benefits of employing the online balancing tool are additionally based on other positive side-effects [2].

3.2. Plausibility check and check of the measured value drift

A plausibility check can be used to determine whether the indicated measured values are correct. In case of big differences within the balances after recalculation, at least one of the measuring units must be incorrectly calibrated or the conversion factor programmed at commissioning is not accurate. Moreover, the drift of the measuring devices can be monitored if online monitoring is carried out within the system. Thus, the system indicates whether one of the measuring instruments operates outside the permissible tolerance range.

3.3. Online calorific value

The system allows the extraction of important parameters from the online balancing tool which cannot be directly measured or with difficulties only. Besides the NO_x raw gas value, this also applies to the calorific value of the combusted waste which is usually calculated as a longer term average from steam production and mass flow of waste. Figure 4 shows the fuel mass flow and calorific value over a period of time. The dotted lines illustrate the values indicated in the control room, including in its calculation time-delayed values of the crane scale. The solid lines are derived from online balancing.

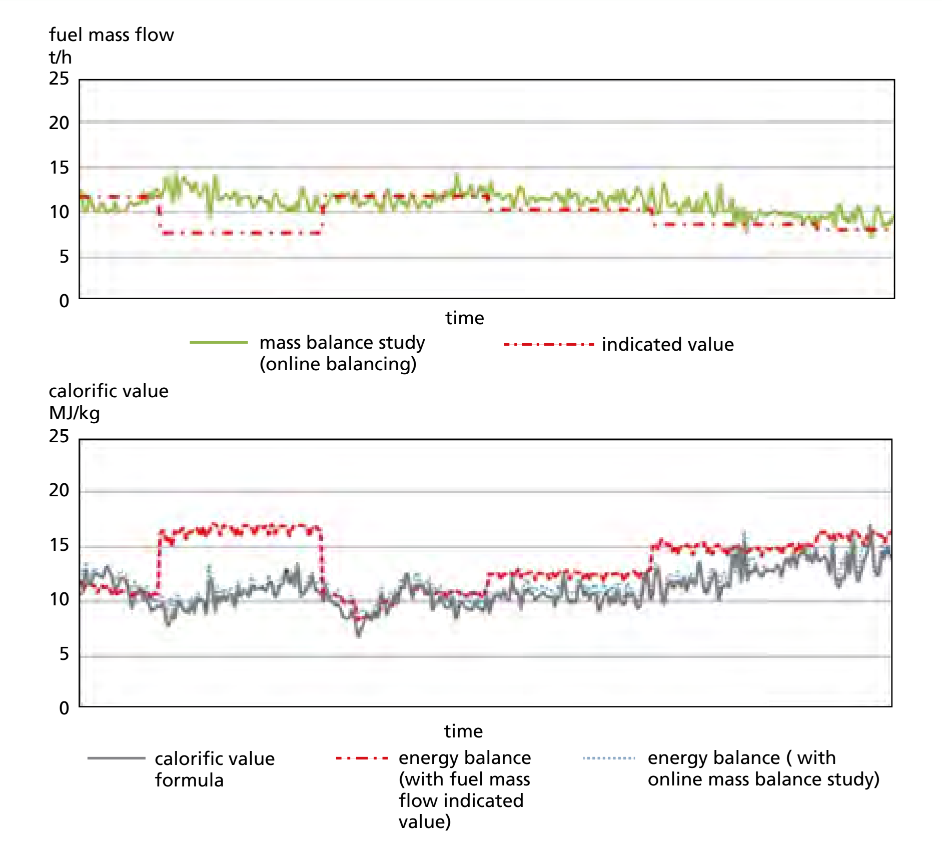

Figure 4: Fuel mass flow and calorific value over period of time

3.4. Fractionation

To determine the NO_x raw gas value, the fractionation of the waste is first approximated. It may be interesting for the operator to record the data on the composition of the waste over the annual course.

4. New Apps for modelling of the grate and denitrification process

After successful testing of the tool and having gained extended experiences with many SNCR installations the next phase of development was started to generate even more detailed information about the process and the raw gas NO_x data. Especially, it would be perfect to know about the NO_x raw gas distribution upstream of the SNCR injection levels in order to inject more reduction agent in zones which contain more NO_x or of course, less into zones with less NO_x. Thus, maximum SNCR performance and minimum reduction agent consumption and ammonia slip could be achieved. Therefore, a new App *Grate Model* was developed and successfully tested.

4.1. Grate model

The new Grate Model App calculates the NO_x concentration of different grate zones. Basically, the grate will be separated into several air zones according to the existing zones of combustion air streams permitting a more differential analysis. Those air streams will be incorporated online into the calculation model. The burn-out behaviour of the fuel in each of these zones is assumed accordingly. Modern camera systems could even supply more detailed input which also could then be used by the model. In general, the burn-out behaviour of many fuel fractions is known from earlier tests and this information is stored in the database of the platform. The waste composition and the respective nitrogen content are already known from the calculations after having applied the online balancing tool. Consequently, a NO_x concentration calculation can be executed for each grate section considering the known combustion air flows, the speed of the grate and the estimated progress of the burn-out of the fuel. Figure 5 shows the set-up of the model.

A set of backward reactor cells is arranged in such a way that the air zones as well as grate track zones can be modelled. Within each of the backward reactors, the combustion reaction and the NO_x formation reactions are executed. Equilibrium is always achieved of each reactor element and the results are the released mass flows of flue gas components as well as the enthalpy for each cell. Therefore, the component profiles of the main components including NO_x as well as temperature across the boiler can be estimated.

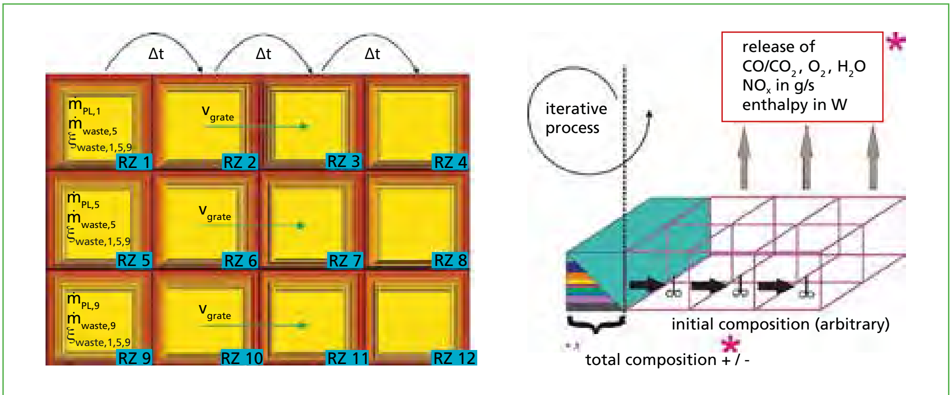

Figure 5: Schematic of the grate model (left); grate model consisting of a defined number of backward reactors (continuous stirred tank reactor elements)(right)

Of course, these results are forming a rough estimate. The overall situation gets even more complex taking into account that secondary air is introduced above the grate zone into the burn out zone of the furnace. However, the injected amounts of secondary air as well as the location of the secondary air nozzles are known and can also be modelled if required. The NO_x formation mechanisms in the burn-out zone are different compared to the ones on the grate. On the grate, mainly fuel-based nitrogen reacts with oxygen to NO_x depending on the local available air surplus (lambda) and the type of nitrogen bounding within the fuel. In the downstream burn-out zone mainly thermal NO_x formation is monitored by means of secondary air injection (Zeldovich-mechanism).

4.2. Spray model

The Spray Model is the second new App which is able to simulate the SNCR injection in real time. This model could also be integrated into the control of the SNCR. The total injection space is separated into a defined number of cells forming the balancing boundaries. Measured and calculated values are related to each of the cells. Figure 6 shows a schematic of the balancing model. During the tests the number of balancing cells was limited to a number of 1,000, i. e. the amount of calculation time was reduced while being sufficiently exact. Geometrical restrictions had not to be considered corresponding to the underlying commercial testing plant geometry resulting in a cuboid. Other furnace geometries can also be modelled. One of the most important input data is the temperature distribution. The flue gas temperature is decisive for droplet evaporation calculation, reaction velocities and retention time within the SNCR reaction zone.

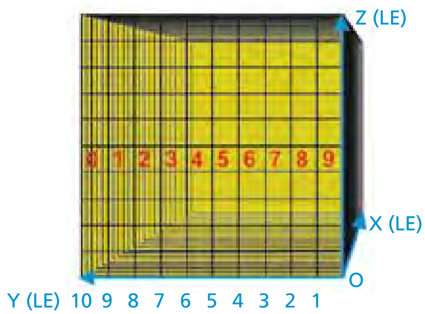

Figure 6:

Grid model of the furnace section of the SNCR injection levels defining the balancing system boundary

The commercial testing plant is equipped with an acoustical temperature measurement. An initial NO_x distribution was known from the testing of the system some time ago. Employing the online temperature data, initial NO_x profile information as well as the knowledge about the characteristic data of the injection nozzle and the usually injected amounts of reduction agent the NO_x reduction inside each of the cells can be calculated. Figure 7 shows a three-dimensional simulation result being based on the injection by means of 4 lances into a four-sided firing space. The size of each single square symbolises the amount of reduction agent which is released after evaporation of the droplets being available for the NO_x reduction reaction. The result of the NO_x reduction is calculated by incorporating the NO_x distribution profile (Figure 8), the measured temperature profile as well as the SNCR reaction mechanisms.

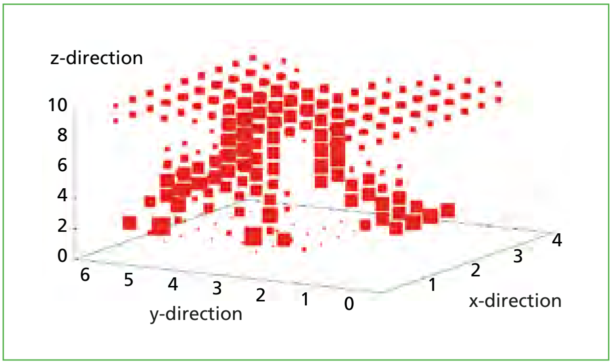

Figure 7:

Calculated amount of reduction agent distribution before reaction with NO_x, symbolised by means of the size of squares, one injection level with 4 injectors in operation

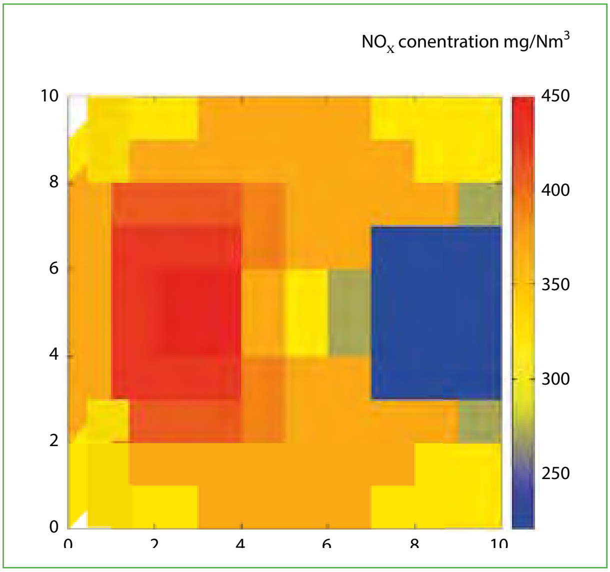

Figure 8:

NO_x-distribution across the furnace section upstream of SNCR

4.3. NO_x-modeling results

In chapter 4.1 the Grate Model was introduced showing how single grate balancing elements are defined.

Figure 9 illustrates the results of the simulation of the NO_x emissions of the different grate zones based on the given amounts of primary air and its assumed distribution.

The NO_x concentration downstream grate zone 1 (heating and drying phase) are significantly below the NO_x concentrations downstream of the grate zone 2 (combustion of volatiles) and grate zone 3 (burn out zone). Due to the lack of a camera monitoring the firing chamber both grate zones 2 and 3 were combined to the same balancing sector. The main amount of NO_x is produced in grate zone 2. The bold red line shows the average NO_x concentration of all zones.

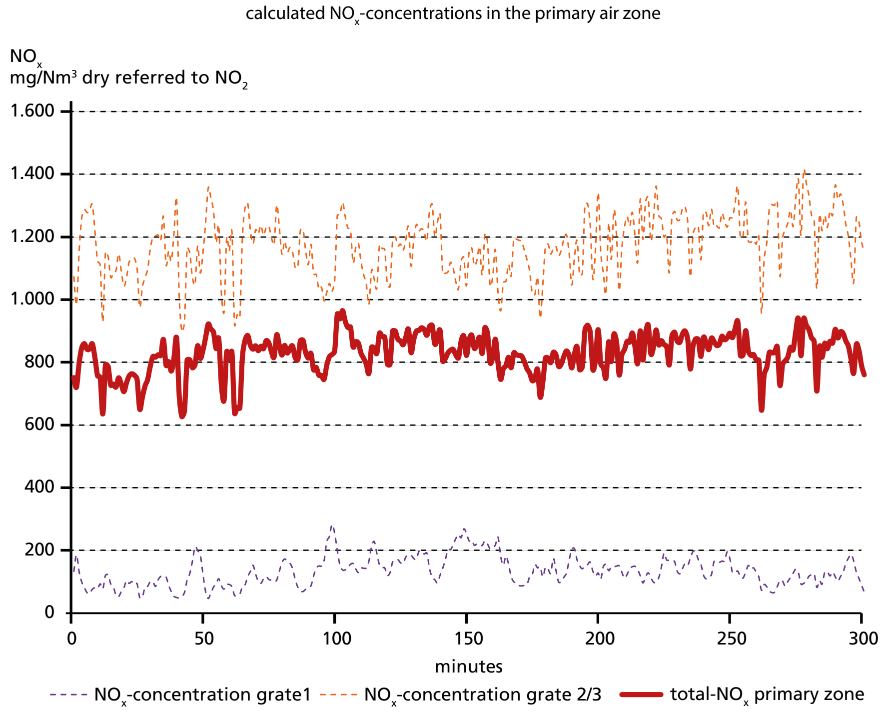

Figure 9: Calculated NO_x-concentrations for different grate zones downstream the primary combustion zone

The diagram in Figure 10 shows the estimated NO_x concentrations downstream the secondary air injection. It is based on the input of the results of the grate zone with primary air injection which was calculated before. The effect of the mixing of secondary air with the flue gas having a very high viscosity at temperatures above 1000°C is based on some reasonable assumptions and it is based on the free jet theory. The impact of the secondary air addition is indicated at the front wall (blue dotted line, lowest line), at the rear wall (grey dotted line, upper line), in the furnace centre line (orange line) and the average line (red bold line). As a result it can clearly be seen that most of the time the NO_x content of the centre line corresponds to the average NO_x raw gas concentration range of 300 – 500 mg/Nm³ which had been known by previous measurements. However, this is not always true. Between minute 50 and 100 the NO_x concentration at the front wall even increases above the centre one for some minutes. During this time the main firing zone was shifted as a consequence from either steep increase of the heating value of the waste or much higher local air surplus promoting NO_x formation inside this zone.

Based on these results the partial NO_x mass flows upstream of the SNCR can be calculated. Up to now, the results of the model have not been validated by means of a NO_x net measurement.

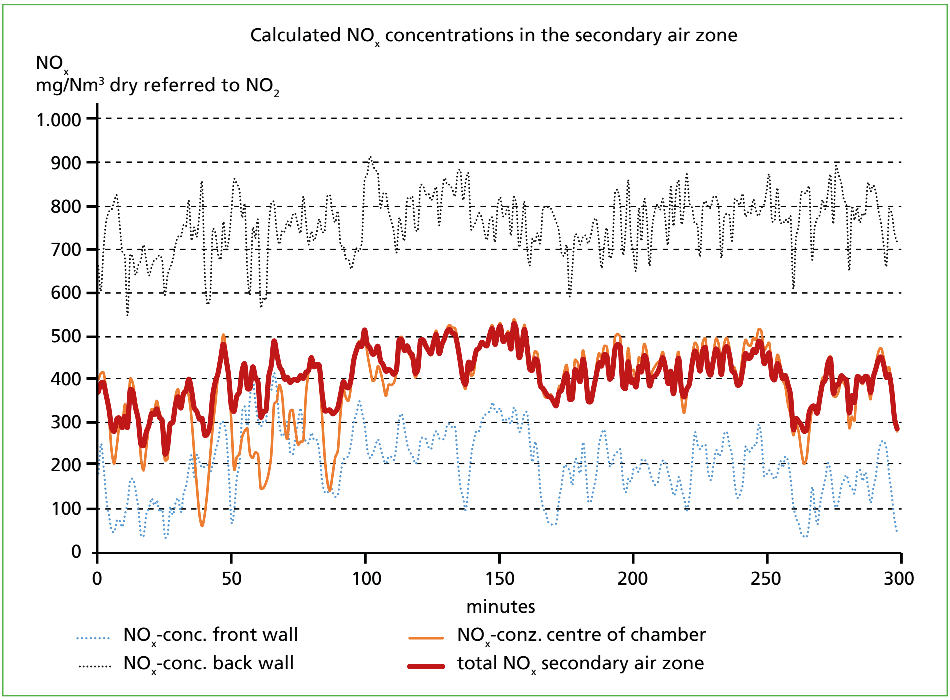

Figure 10: Calculated NO_x-concentrations downstream the secondary air injection zone

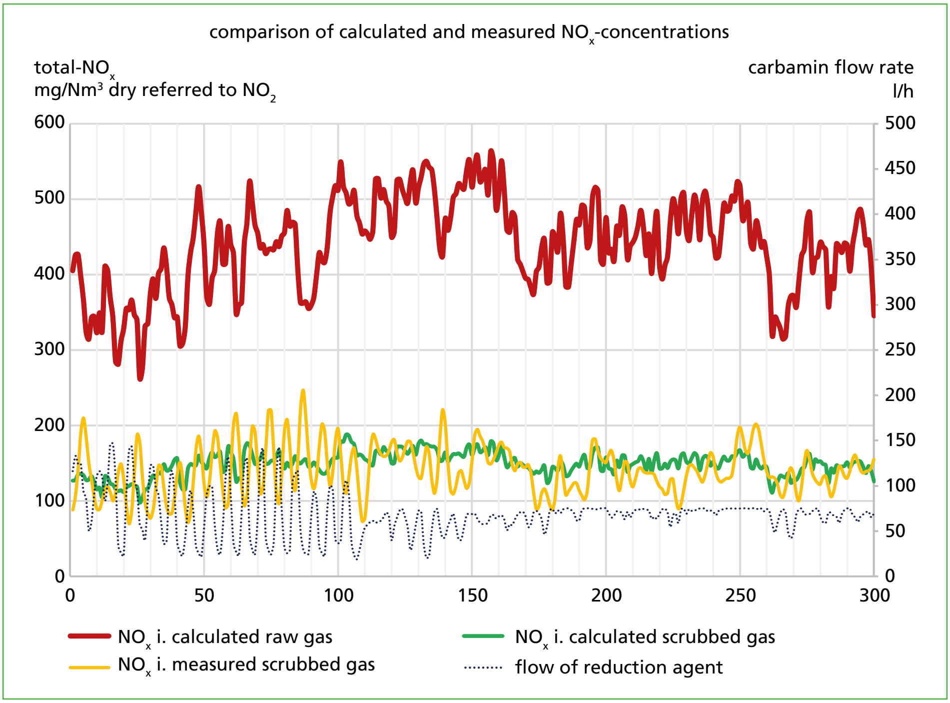

Figure 11: Calculated and measured total NO_x-concentrations

Figure 11 shows the calculated average NO_x concentrations of the raw gas (bold red line) and downstream of the SNCR of the clean gas (green line). In addition, the measured NO_x concentration of the clean gas (yellow line) as well as the reduction agent flow rate (dotted grey line).

The control of the SNCR is heavily oscillating in the beginning up to minute 110. Initially, it was operated by means of applying the old conventional control concept. Then, the control concept was changed to a new one including NO_x-raw gas concentration prediction. The reduction agent feeding is more constant, oscillation effects are less and the amount of reduction agent is lowered. It has to be mentioned that the currently installed SNCR technology cannot completely follow the potential of the new controller because it is not possible to control the flow of reaction agent to each of the single lances individually. This would be necessary in order to adapt the reduction agent flow to the partial available NO_x mass flow of the respective furnace cross section.

Unfortunately, it has not been possible up to now to test the new furnace model with switched-off SNCR in order to compare the calculated raw gas NO_x concentrations with measured values.

The Spray Model as described in Chapter 4.2 was applied to simulate the result of the SNCR process. Starting with minute 110, the calculated clean gas values well correspond to the measured NO_x-value. The quality of the controller is improved and the injection of the reduction agent harmonised. This application demonstrates the potential of the new system and its Apps.

5. Conclusion

For the first time an open and well-structured platform is available as an universal base for monitoring programs. Focus was put on stability, IT security and compatibility. The user of the platform receives a base for important applications which visualise the factors impacting the plant operation and the resulting control recommendations. Extensions with new Apps are easily possible due to defined interfaces and a universal structure.

New Apps were developed and tested. The Grate Model permits zone-wise calculation of the NO_x raw gas concentration and consequently, targeted dosing of Selective Non Catalytic Reduction (SNCR) reduction agent for the first time. Savings of reduction agent and less ammonia slip can be achieved. Even for challenging denitrification problems it will be possible to meet reduced NO_x emission limits. However, it has to be checked whether the installed SNCR hardware has to be adapted to be suitable for the proposed control actions.

The new Spray Model is a very supportive tool for SNCR design and operation. Simulation of the results of switching single lances to better fit to the raw gas NO_x profile and furnace cross section temperatures are a helpful means for optimisation. It also predicts the NO_x clean gas values downstream of the SNCR by corresponding well with measured data.

Conflicting targets of plant operation are sometimes requiring contradicting measures. An expert system being an additional tool of the platform would be able to provide rules and algorithms to consult the operators. The best compromise would be proposed considering the boundary conditions of the specific plant and changing fuel qualities. The underlying algorithms would rely on information and measured values which are available through the overall monitoring system.

Acknowledgement

The authors wish to thank various people and institutions for their contributions to this project; especially to AIF Projekt GmbH for their financing support and to the Institute of Power Engineering, TU Dresden being the scientific partner of this project.

6. References

[1] Beckmann, M.: Wirtschaftliche Potentiale des Online-Anlagen-Monitorings. In: Thomé-Kozmiensky, K.; Beckmann, M. (Eds.): Energie aus Abfall. Neuruppin : TK Verlag Karl Thomé-Kozmiensky, 2015

[2] Pohl, M.: Vom Brennstoff zum Rauchgas über Combustion 4.0. In: Kraftwerkstechnik. Dresden,Saxonia, 2015

[3] Reynolds, P.; Günther, C.: Technisches und Wirtschaftliches Potenzial der Online-Bilanzierung. In: Thomé-Kozmiensky, K.; Beckmann, M.: Energie aus Abfall Band 13. Neuruppin : TK Verlag Karl Thomé Kozmiensky, 2016

[4] Schüttenhelm, W.; Reynolds, P.: SNCR Technology to Meet Challenging NO_x-Reduction Requirements. In: Thomé-Kozmiensky, et al. (Eds.): Waste managment Volume 7. Neuruppin: TK Verlag Karl Thomé Kozmiensky, 2017

[5] Schüttenhelm, W.; Reynolds, P.; Hukriede, J.: Einhaltung verschärfter NO_x- und NH_3-Grenzwerte bei bestehenden Anlagen - Vorgehen und Lösungsansätze anhand von Praxisbeispielen. In: Thomé-Kozmiensky, K.; Beckmann, M.(Eds.): Energie aus Abfall Band 12. Berlin : TK Verlag Karl Thomé Kozmiensky, 2015

[6] Schüttenhelm, W.; Reynolds, P.: SNCR for Low NO_x Emissions - Case Study of a Swedish Waste-to-Energy plant. In: Thomé-Kozmiensky, et al. (Eds.): Waste managment Volume 5. Neuruppin: TK Verlag Karl Thomé Kozmiensky, 2015

Contact Person

Dr.-Ing. Wolfgang Schüttenhelm
WS Management & Engineering (haftungsbeschränkt)
Siefener Straße 26
51674 Wiehl
GERMANY
Phone: 0049 - 22 62 - 712 63 74
Email: wolfgang.schuettenhelm@t-online.de

Other Institutions

ERC GmbH
Bäcker Straße 11-13
21244 Buchholz i.d. Nordheide
GERMANY
Phone: 0049 - 4181 - 100
E-Mail: office@erc-online.de

Bibliografische Information der Deutschen Nationalbibliothek

Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.dnb.de abrufbar

Thiel, S.; Thomé-Kozmiensky, E.; Winter, F.; Juchelková, D. (Eds.):

Waste Management, Volume 8
– Waste-to-Energy –

ISBN 978-3-944310-42-8 Thomé-Kozmiensky Verlag GmbH

Publisher: Thomé-Kozmiensky Verlag GmbH • Neuruppin 2018

Editorial office: Dr.-Ing. Stephanie Thiel, Dr.-Ing. Olaf Holm,
Elisabeth Thomé-Kozmiensky, M.Sc.

Layout: Janin Burbott-Seidel, Ginette Teske, Roland Richter, Cordula Müller,
Sarah Pietsch, Gabi Spiegel, Lena Bischkopf

Printing: Universal Medien GmbH, Munich