Optimisation of the SNCR-DENOX Method Using Diode Laser Spectroscopy

Kurzfassung

Optimierung des SNCR-DENOX-Verfahrens mittels Diodenlaser-Spektroskopie

Beim SNCR-DENOX-Verfahren werden die Stickoxide in Rauchgasen von Verbrennungsanlagen durch eine dosierte Zugabe von NH_3-haltigen Reduktionsmitteln bei Gastemperaturen um 950 °C deutlich vermindert. Eine überstöchiometrische Zugabe von NH_3 führt hier zu unnötigen Ammoniakverbrauch und zu NH_3-Schlupf durch unverbrauchtes Reduktionsmittel. Die Folge sind unerwünschte Effekte wie Geruchsbelästigung oder Salzablagerungen an nachgeschalteten Anlagenteilen. Der vorliegende Artikel zeigt, wie SNCR-DENOX-Anlagen in der verbrennungstechnischen Praxis mittels einer schnellen, Diodenlaser gestützten NH_3-Schlupfmessung und einem Fuzzy-Regler hinsichtlich Effektivität, Verbrauchsmittelkosten und Schlupfminimierung entscheidend verbessert werden können. Bei der in der beschriebenen Weise optimierten SNCR-DENOX-Anlage der Müllverwertungsanlage Rugenberger Damm (MVR) Hamburg konnte im Regelbetrieb an zwei Verbrennungslinien der Reduktionsmittelverbrauch im Mittel um etwa 25 % und der NH_3-Schlupf um etwa 50 % reduziert werden, bei gleichzeitig maximalem Reaktionsumsatz der Stickoxide von >80 %.

Das moderne Regelkonzept mit der schnellen In-Situ-NH_3-Schlupfmessung mit dem Siemens Diodenlaser-Spektrometer LDS 3000 und einem speziellen Fuzzy-Regler wurde bei der MVA Hamburg im Test- wie im Regelbetrieb validiert. Die positiven Langzeiterfahrungen hinsichtlich Regelverhalten und Betriebsaufwand lassen die hier beschriebene Schlupfregelung als Standardverfahren für die Regelung von Hochleistungs-SNCR-Anlagen geeignet erscheinen.

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Introduction

The SNCR-DENOX method is a widely used, efficient method with relatively low investment and operating costs for the removal of nitrogen oxides from flue gases of large-scale furnace systems. Liquid reducing agents containing ammonia are sprayed directly into the hot flue gases of a combustion plant. The spontaneous chemical reactions of the reducing agent with the nitrogen oxides NO and NO_2, which take place at temperatures of about 950 °C, reduce these to nitrogen and water. Overstoichiometric reducing agent or agent introduced in the wrong temperature window remain unused as NH_3 slip in the flue gas and causes problems – in addition to unnecessarily high cost for such consumables and ammonia emissions – due to the formation of ammonia salt deposits on the plant parts downstream of the DENOX. Municipal waste incineration plants with their constantly changing combustion conditions and flue gas compositions place high demands on the control of an SNCR plant if high NO_x turnover rates and simultaneously low NH_3 consumption and slip values are to be achieved. This article describes a modern control concept based on laser technology and fuzzy logic for SNCR-DENOX plants and their application in industrial processes using the Rugenberger Damm waste incineration plant (WIP) in Hamburg as an example.

The Plant Concept of the WIP

The Hamburg WIP operates two identical combustion lines for thermal decomposition of primary domestic waste with a nominal annual capacity of 320 000 t/a at the Rugenberger Damm site (Figure 1). About 21.5 tons of waste per combustion line are incinerated every hour on a two-level grate firing.

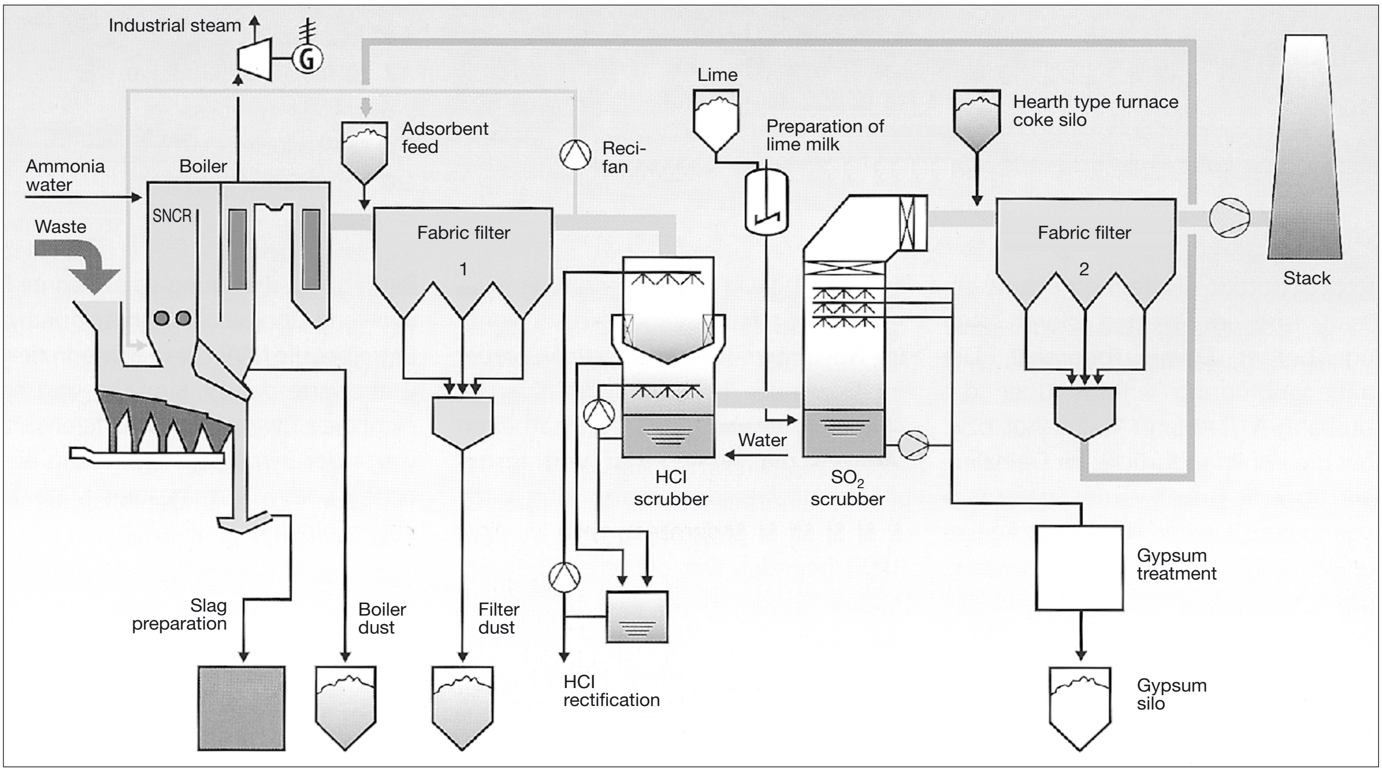

Figure 1. The plant concept of the Hamburg WIP.

The hot flue gases pass the four vertical flues of the steam generator before being transferred to the respective flue gas purification plants. Up to 68 tons of fresh steam are generated per combustion line and hour which are used in the form of process steam and electricity.

Waste gas purification begins already in the boiler with the SNCR-DENOX and a high-temperature cyclone between the 2nd and 3rd or the 3rd and 4th boiler flue. After leaving the boiler, weakly contaminated open hearth coke (OHC) from the particle filter 2 is added to the waste gas which is removed together with the rest of the fly ash of the flue gas in particle filter 1.

To separate the halogen content, the flue gas runs through a double-stage acid scrubber and to separate the sulphuric oxides through a 1-stage alkaline scrubber after which it reaches the post-purification stage. Here, OHC is added as an adsorbent and separated again in fabric filter 2 before the flue gases are fed into the stack by suction fans. As a special process engineering feature, the WIP operates an HCl-rectification plant in which the 10 to 12 % raw hydrochloric acid produced in the acid washer is concentrated and purified into marketable hydrochloric acid of at least 30 %. As can be seen from the plant concept, the WIP has no problems at all with gaseous ammonia emissions due to too high slip values of the SNCR-plant because these remain in the scrubber. However, the ammonia separated here causes problems due to the formation of ammonia salts mainly on certain plant components of the HCl rectification which demands the best possible slip monitoring and control equipment.

The SNCR-DENOX Plant
(Figure 2)

The WIP has three spray nozzle openings each in three levels of the first boiler flue for a 25 % watery solution of ammonia which can be controlled individually. The optimum reaction window for the reduction of nitrogen oxides in the flue gas by NH_3 is at about 950 °C. Too low temperatures lead to an incomplete reaction turnover whereas at too high temperatures the reducing agent ammonia reacts with oxygen to produce NO_x and therefore increases instead of decreasing the nitrogen oxides. The WIP uses an acoustic measuring method to determine the flue gas temperature distribution over the cross-section of the 1st flue in order to identify the respective optimum injection level. The amount of ammonia added is controlled conventionally by the reaction turnover of the nitrogen oxide, i.e. by the NO_x concentration behind the DENOX. The WIP has an extractive gas tap at the transition between the 3rd and the 4th boiler flue. However, the measuring times of commercially available extractive NO analysers are too long in comparison with the high dynamic of the combustion process to allow good control of the current flue gas stoichiometries. Additionally, using NO as the control variable is unfavourable since NO has a very flat gradient at the operating point of the DENOX. Unlike this, NH_3 slip can only be measured at an overstoichiometric addition of ammonia and is therefore a clear indication of excessive ammonia injection. Therefore, a set point is chosen with a slip control at different NH_3 slip values which are as small as possible but not zero to obtain a maximum reaction turnover of the nitrogen oxide.

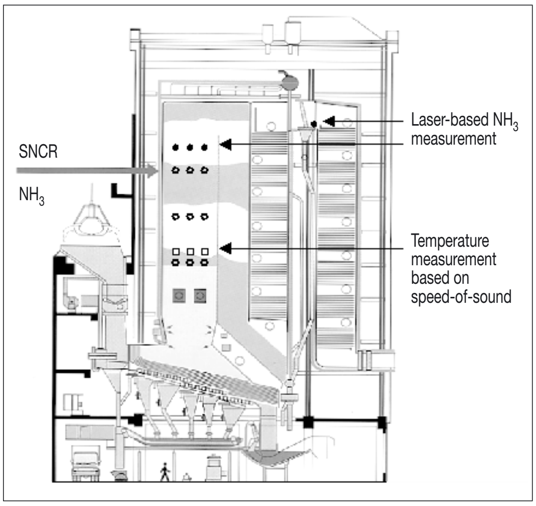

Figure 2. The SNCR plant of the WIP.

The Initial Situation

The operating permit of the WIP provides for a limit value of 100 mg/Nm³ NO_x (s.t.p.) as a daily average. This value is half of the general limit value for waste incineration plants prescribed by the 17th BImSchV (Federal Immission Control Act). If one wishes to stay below this low limit in the long term, the SNCR-DENOX needs to be operated with maximum possible efficiency. The goal here is to add ammonia at sub-stoichiometric conditions. However, as a result of the slow conventional control system, an NH_3 lead value is obtained which results in a usually considerably overstoichiometric addition, i.e. too high ammonia consumption and relatively high NH_3 slip amounting to an average of 25 to 30 mg/Nm³.

Although this ensures that the maximum NO_x daily averages are safely maintained, the price is high ammonia costs and significant maintenance expenses on parts of the HCl-rectification contaminated by ammonia salts.

The Optimisation Concept

The initial idea behind the optimisation concept was to overcome the sluggishness of the existing control system and to be able to achieve an ammonia addition which constantly meets the requirements by means of a fast, close-to-the-process control of ammonia addition in the SNCR plant on the basis of a laser-diode fiber-optic in-situ measurement of the NH_3 slip and a special fuzzy controller.

NH_3 Slip Control Using Diode Laser Spectrometry

By using optical spectroscopic gas analysers like the Siemens LDS 3000 diode laser spectrometer, it is possible to determine the ammonia concentration in situ, i.e. without extractive gas tapping directly in the process and thus to achieve response times of a few seconds at verification limits below 1 ppm NH_3.

The measuring principle which gets its information from the spectral analysis of a single NH_3 molecular absorption line is virtually free of influences from the variable composition or fluctuating dust-laden condition of the process gas (Figure 3). The laser is located in the central unit CU 3000 together with its control, the evaluation computer and the

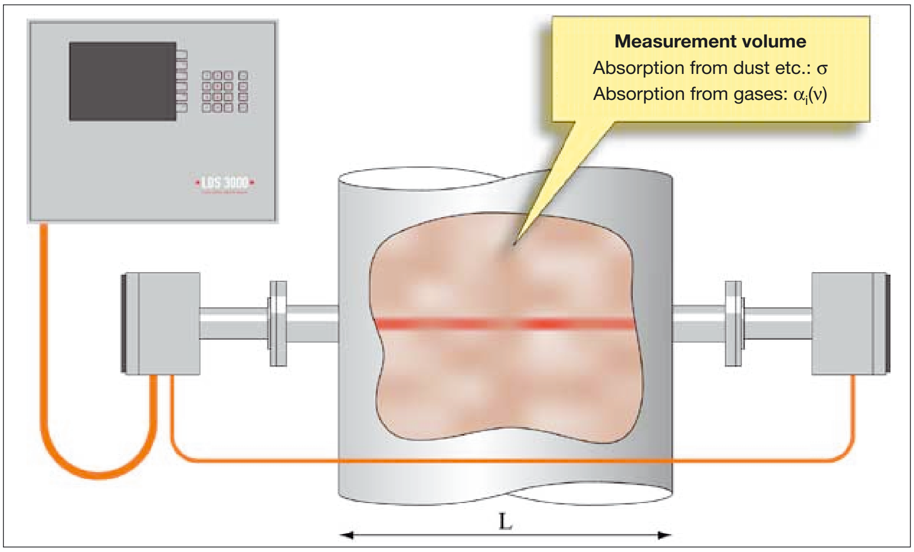

Figure 3. Structure of the LDS 3000 diode laser spectrometer: basic unit with laser module; CU 3000, fiber-optic cable FC 3001, in-situ sensors CD 3002.

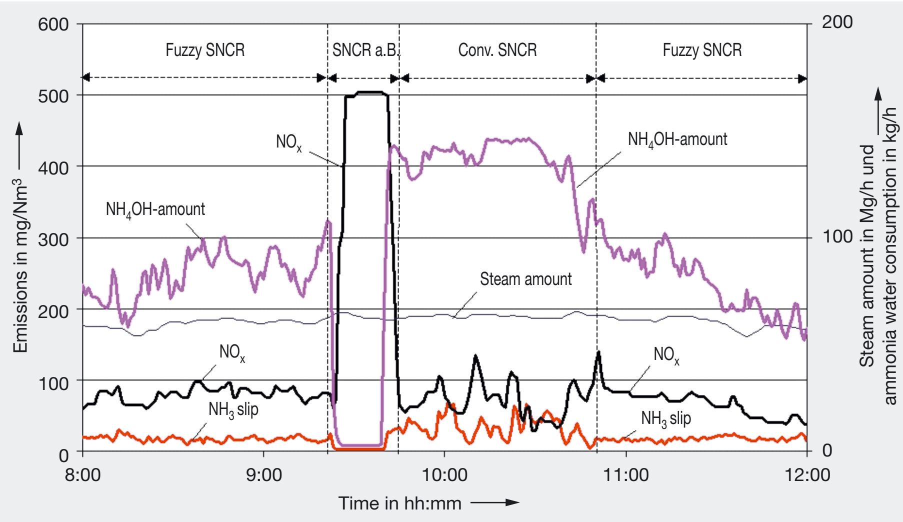

Figure 4. Results of a test run with optimised SNCR-DENOX, without DENOX, with conventional SNCR-DENOX control and again with optimised DENOX [2].

user interface. The laser light and the useful signal are transmitted to the in-situ sensor heads CD 3002 at the measuring point by a special fibre-optic cable FC 3001. The power supply to the detector electronics in the receiver is also carried by this connecting cable by means of two shielded copper wires. The sensors merely form the optical-mechanical interface to the process as a transmitter/receiver configuration. This is the best possible separation of the measuring technology from the frequently very harsh conditions at the measuring point. This concept increases the degree of robustness and flexibility of the laser measurement for applications in industrial process plants. With a fibre-optic beam splitter in the laser module inside the central unit it is possible to control and simultaneously evaluate three measuring points with just one analyser. At the measuring point, only the process flange of dimension DN65/PN6 and a connection facility for a purging medium such as instrument air need to be set up. Maintenance is restricted to occasional cleaning of the process side surfaces of the sensor windows made of chemically- and mechanically-resistant quartz glass. By using a maintenance-free reference gas cell in the basic device there is no need for calibration of the measuring instrument at the application site. The LDS 3000 measures with a repetition rate of 50 spectra per second and therefore achieves a real time measurement of the current process conditions regarding the NH_3 slip. Four NH_3 measuring points are set up per combustion line. One measuring point is in the transition between the 3rd and 4th flue of the boiler and is used for measuring the total NH_3 slip. Three measuring points in the 1st flue mounted above the last ammonia injection opening allow location-independent measurement of the local NH_3 distribution at the end of the actual reaction zone. This provides enough information together with the acoustic measurement of the temperature distribution in the 1st boiler flue to be able to control the 9 NH_3 injections individually in position and amount.

Fuzzy Controller

To efficiently transfer this high information density to a fast, close-to-the-process control, a fuzzy controller specially designed for this purpose by Babcock Borsig Power Environment GmbH, Gummersbach, is used. Based on the available process variables such as temperature distribution, ammonia addition, ammonia slip at the four measuring points at the end of the reaction zone and at the end of the boiler and the NO_x concentration after the DENOX, the control gives both the best choice of active injection openings, the individual NH_3 quantity control and the limit value monitoring for the nitrogen oxides in real time.

Results of a Test Run/ Long-term Experience

The amount of improvement of the SNCR-DENOX in comparison with the conventional control with an extractive NO concentration measurement in raw gas was impressively proven by a test run, Figure 4. First the plant was operated in optimised mode with NH_3 laser measurement and fuzzy controller. It exhibited a very stable operation with low NH_3 slip values and a NO_x concentration always well below the limit value of 100 mg/Nm^3. The ammonia addition was then switched off to determine the NO_x raw gas content. After a short time a value of about 500 mg/Nm^3 NO_x was established.

The SNCR-DENOX plant was then restarted initially in conventional mode and left in this operating mode for a certain time. In comparison with the optimised operation at the beginning of the test run, the ammonia consumption was now higher by almost a factor of two which was also reflected in much higher NH_3 slip values. The NO_x concentration values remain safely below the limit for the daily mean values on average but a few "strays" are apparent which briefly drop well below or considerably exceed the mean value. Both events, the result of ammonia under-injection or over-injection, can be accurately predicted on the basis of the NH_3 slip signal which behaves oppositely because this information is available a few minutes earlier.

Resuming the optimised mode clearly shows the effect of the fast slip control which has an immediate positive effect on both the ammonia consumption, the NO_x values and on the NH_3 slip. A 20 to 30 % reduction in the amount of ammonia consumed was achieved in this way. The set point for the slip was chosen at approximately 12 mg/Nm^3 NH_3 which is equivalent to a reduction of 50 to 70 % in relation to the slip values in conventional operation. Daily averages of 80 mg/Nm^3 for the nitrogen oxides were still safely maintained with a simultaneously marked reduction and smoothing of the half hourly averages . The optimised SNCR plant has been in regular operation in both combustion lines since May 2001 and has been operating reliably and with minimum maintenance since then. The reductions in consumption and slip illustrated in the test run could also be verified under the long-term operation. The aim of the optimisation process, to considerably reduce the NH_3 slip and the ammonia consumption without negatively affecting the NO_x reduction was successfully achieved.

Summary

A modern control concept for SNCR-DENOX plants, based on a fast in-situ NH_3 slip measurement with the Siemens LDS 3000 diode laser spectrometer and a special fuzzy controller was successfully introduced at the WIP Rugenberger Damm in Hamburg and validated in tests and in regular operation. The envisaged goal of a significant reduction in slip and ammonia consumption at full performance of the nitrogen oxide reduction was achieved by individual dosing of the reducing agent constantly adapted to prevailing local requirements. It seems that the positive long-term findings in terms of control behaviour and operating expenses make the slip control described here a suitable standard method of controlling high-performance SNCR plants.

References

[1] WIP Hamburg, Environment Report 2000.

[2] *Zwahr, H.:* Using NIR-Laser Spectroscopy in the SNCR Technique. VDI-Reports No. 1667, pp. 9–14 (2002).