A friend to the environment

K.P. Schloeder and S. Schmid, Dyckerhoff GmbH, and M. Giavazzi and L. Maiocchi, Boldrocchi Srl, show how two companies joined forces to implement a selective catalytic reduction (SCR) system at the Deuna cement plant in order to reduce NO_x emissions.

The production of cement is a high temperature process, involving the emission of nitrogen oxides (NO_x). As these are polluting compounds which contribute to the formation of smog and acid rain, an increasing number of countries have tightened controls over NO_x emissions within the cement industry. Germany is leading the way with NO_x limits of 200 mg/Nm^3 (daily mean) for cement clinker kilns with waste co-incineration.

Deuna's cement plant in Thuringia, owned by the Buzzi Unicem company Dyckerhoff, produces approximately 2400 tpd of clinker. The existing selective non-catalytic reduction (SNCR) system was not able to reduce emissions significantly enough to achieve the new permitted limits on NO_x and NH_3; a selective catalytic reduction (SCR) system was therefore necessary.

Milan-based Boldrocchi designed and installed a tailor-made SCR system for high dust environments (the reduction takes place in the dust-laden exhaust gas), complete with a catalyst reactor using ammonia water as a reagent, soot blowers and a compressed air station. Commissioning took place during the summer of 2019 and, after a fine-tuning period necessary to optimise the soot blowing system and the overall process, the SCR system was deemed fit for operation. The system is now currently in stable operation and reduces emissions well within the limits of the German Emission Protection Act (17th BlmSchV).

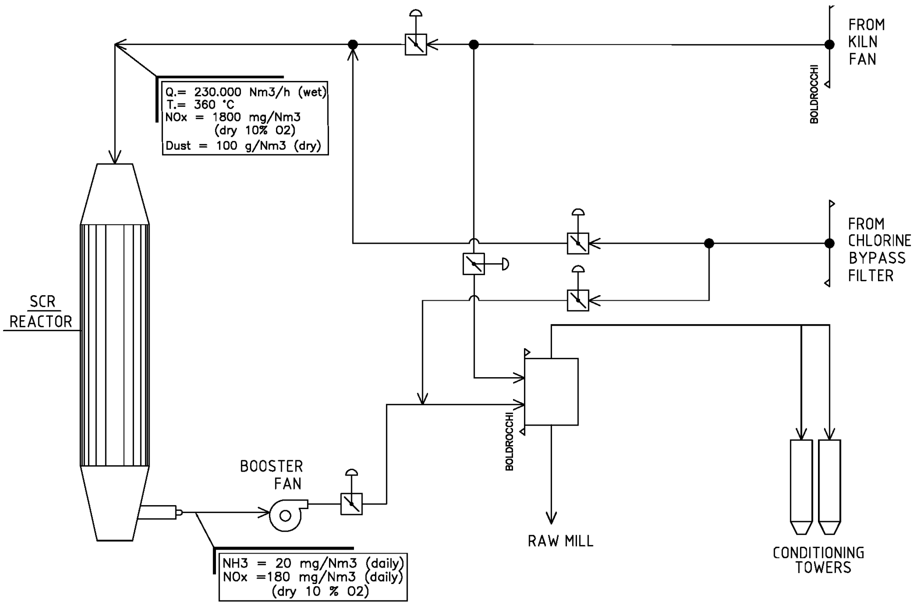

Figure 1. Plant flowsheet.

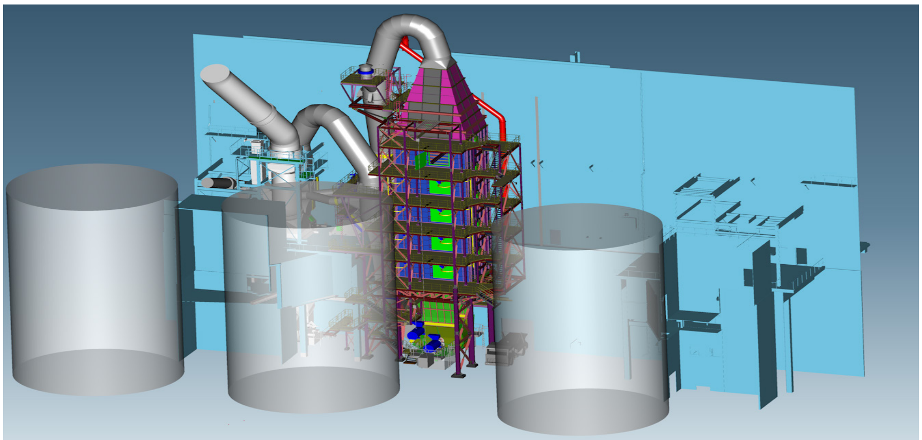

Figure 2. 3D model.

Background

Nitrogen oxide emissions have been a known environmental issue for years and many clinker production kilns around the world have had to incorporate technologies to limit such emissions. Various emission abatement technologies – from process optimisation to secondary measures – have been developed following the requests of European Directives and local norms. In 2010, the European Directive 2010/75/EU defined emission limit values for cement plants co-incinerating waste. In Germany, the Ordinance on Waste Incineration and Co-Incineration (17th BlmSchV) implemented the European Norm by defining NO_x emission limits for German Cement Kilns with Waste Co-incineration between 200 mg/Nm³ (daily average, dry gas, 10% oxygen) and 400 mg/Nm³ (half hourly average, dry gas, 10% oxygen).

The ammonia emission limit was also tightened, making it difficult to meet both NO_x and NH_3 emission limit values with primary measures or even SNCR processes. SNCR is limited in terms of NO_x removal efficiency and, when pushed to its limit, it can cause high ammonia emissions (slip). It has meant that SCR systems – the state-of-the-art for NO_x reduction in the power sector and for municipal incinerators – have had to be adapted to the cement production process, to replace, or act in conjunction with, existing SNCR systems.

The choice of a $DeNO_x$ system for Deuna

At the Deuna cement plant, the previous SNCR system was altogether replaced with a SCR reactor in which the catalyst allows the reaction between NO_x and NH_3 at lower temperatures – and with higher efficiency – than in the SNCR process.

The catalyst allows reactions to occur in a temperature window of 300 – 400°C. The kiln preheater exit gas is therefore set to this temperature range. Positioning the reactor just after the kiln fan (the so-called ‘high dust arrangement’) was determined to be best for maximum reaction efficiency (Figure 1). There is an issue with this positioning, however: the kiln gas dust load reaches up to 100 gr/Nm^3, meaning the soot blowing system must be properly designed to avoid catalyst clogging. Additionally, Boldrocchi has found that an expressly designed preheating system allows operators to manage the kiln start-up operations and transitory phases, avoiding the risk of catalyst deactivation due to improper process conditions.

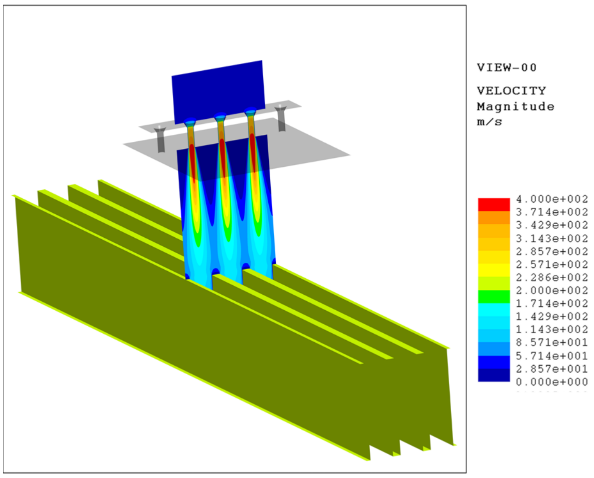

Figure 3. Soot Blowing.

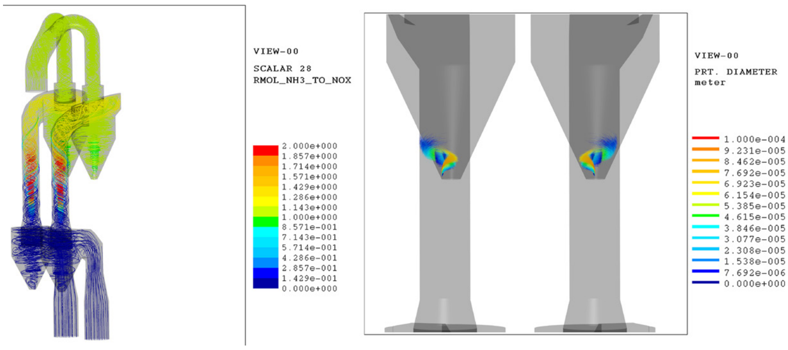

Figure 4. Ammonia Injection.

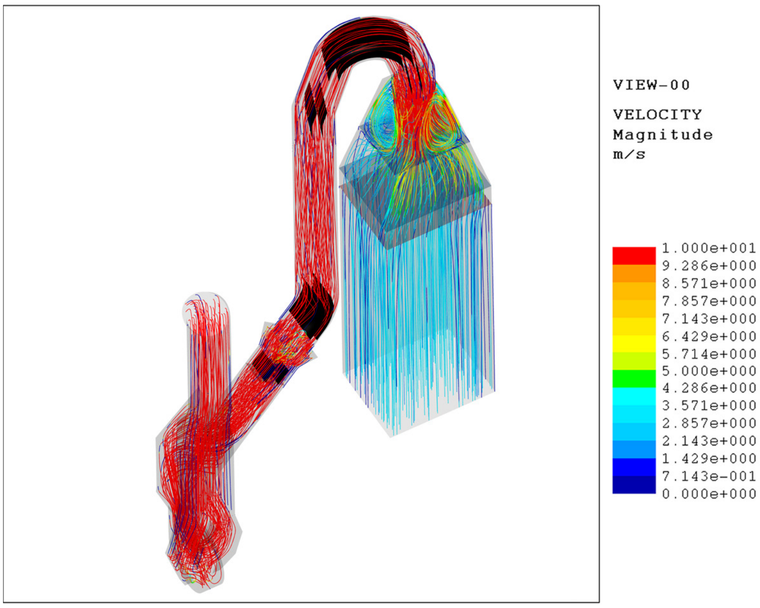

Figure 5. Gas path.

The team

Dyckerhoff, a Buzzi Unicem company, is an international producer of cement and ready-mixed concrete, operating in Germany, Luxembourg, the Netherlands, Poland, the Czech Republic and Slovakia as well as in Russia and the Ukraine. Buzzi Unicem is a corporation located in Italy, which operates plants in 14 countries, with more than 10 000 employees worldwide.

Before most countries had even introduced environmental emissions legislation, in 1909 Boldrocchi started to manufacture heavy-duty fans and by 1914, the company was developing heat exchangers and air filtration equipment to reduce dust emissions. Since that first filter in 1914, Boldrocchi has grown considerably, now with products in 180 countries and offices in eight. Decades of experience and a continued significant investment in R&D has led the company to develop several innovations, including systems that can achieve almost zero-dust emissions (0.1 mg/Nm^3) while significantly reducing NO_x (40 mg/Nm^3).

Fine-tuning such a technology to achieve optimal performance requires cooperation between the manufacturing company and the client. With a common purpose and leveraging complementary knowledge, Dyckerhoff and Boldrocchi joined forces to implement Boldrocchi’s SCR system at the Deuna cement plant. Thanks to the availability of the Dyckerhoff team and their willingness to share their knowledge of the cement production process, Boldrocchi’s experts were able to overcome obstacles encountered during the assembly and start-up phases. The final outcome: Boldrocchi developed an integrated high dust SCR system, reducing NO_x to 180 mg/Nm^3 with a tailor-made system, suitable and integrated with existing facilities, with minimal ammonia slip.

The design

The project’s main objectives were to:

- Design a carefully considered SCR system to obtain maximum pollutant reduction, process efficiency and plant reliability.

- Engineer a soot-blowing system using software modelling tools, in order to evaluate the system's dust removal efficiency in all operating conditions.
- Pay close attention to the gases' fluid dynamics in order to ensure an optimal catalyst surface with a minimum variation in gas temperature and speed, as well as the correct NO_X/NH_3 molar ratio.
- Find a method to install the new reactor in a very narrow space between the kiln fan and the raw mill building (Figure 2).
- Integrate the SCR system perfectly with the existing equipment and re-use the entire contents of the ammonia storage and dosing system.

The decision to use a high dust SCR system was mainly due to the optimal reaction temperature it offers and the lower complexity of the entire system, compared to a Tail-End solution. A key factor to the proper design of a High Dust SCR system is the catalyst cleaning efficiency as the dust load is very high. The soot blowing system was completely re-engineered using in-house computational fluid dynamic (CFD) simulations and calculations. The team started their CFD analysis using mid-dust environment applications and this improved the efficiency and efficacy for high dust loads (Figure 3). A fully integrated system was designed and supplied which included a compressed air generation station, a distribution net and automation logics. A central distributed control system (DCS) controls the catalyst layers' differential pressure and drives the soot blowing rack with optimal speed and air flow. The latter is produced by one fixed-speed air compressor and one variable-speed air compressor which modifies the velocity to optimise soot removal from the catalyst surface.

CFD tools were also used in order to optimise the ammonia injection (Figure 4) and the gas flow at the catalyst surface (Figure 5). Velocity distribution (which also directly influences the temperature distribution) and the distribution of the molar ratio between NH_3 and NO_X had to be optimised in order to assess the uniformity of the gas at the inlet of the catalyst layer. The parameter used for the analysis of these processes was the coefficient of variation. The 'velocity coefficient of variation' of this system usually ranges from 10 to 20%, while the 'molar ratio coefficient of variation' is between 5 to 10%. Determining the optimal ammonia injection point, the hood design and the placement of deflectors and perforated plates inside the reactor for this project allowed the team to obtain about 8% 'velocity coefficient of variation' and less than 1% 'molar ratio coefficient of variation', leading to a significant performance increase for the SCR system at Deuna.

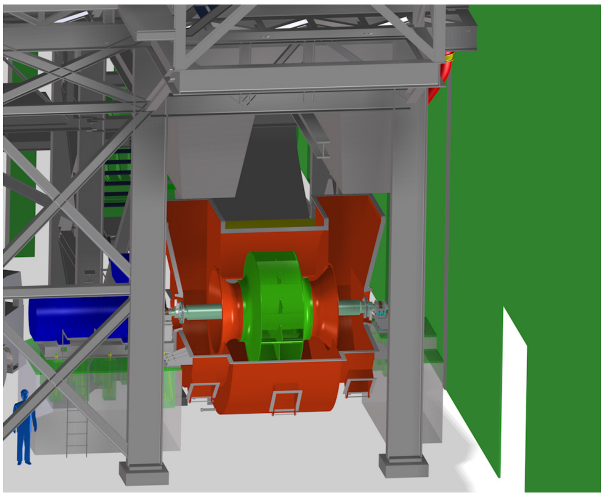

Figure 6. Fan maintenance.

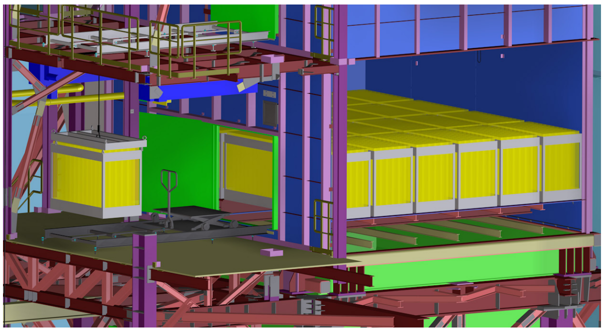

Figure 7. Catalyst maintenance.

Figure 8. Assembly.

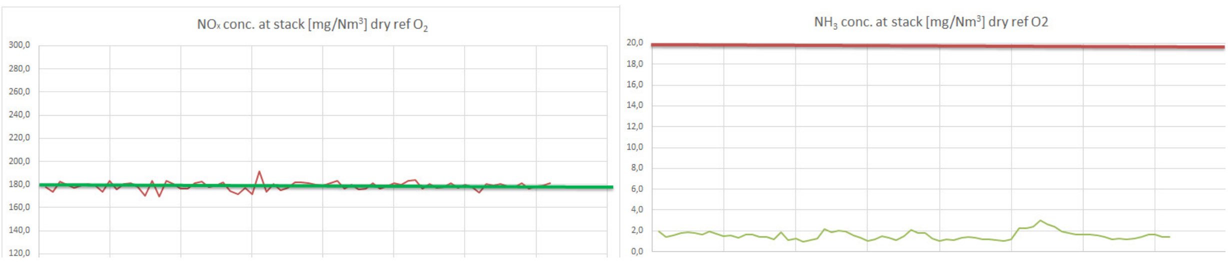

Figure 9. Emissions.

Design and installation given space constraints

Each project is site specific and its execution is influenced by available space and local conditions such as weather, labour supply, local building codes, etc. In both design and construction, numerous operational tasks are inter-dependent, and design must be based on construction and maintenance constraints.

At Deuna, the assembly procedures required particular attention due to the narrow space available between the concrete silos and the existing kiln facilities. For this reason, an integrated approach of design/construction was followed: these processes were considered as an integrated system. Every assembly and maintenance procedure was preliminarily tested by means of 3D simulations and animations (Figures 6 and 7). Furthermore, great attention was paid to the review of the designs with regard to their constructability, in order to elaborate a proper scheme to erect such an unconventional structure (Figure 8). The construction plan was critical and various scenarios were examined to limit the assembly's interference on the production process and to coordinate with a scheduled plant shut down. The sequence of assembly saw the team erect the entire support structure, the reactor and the ducts while the kiln was in operation. Only the interconnection of the new system with existing ductwork was required the kiln to be stopped.

Another major consideration for this project, in order to not hamper production capabilities, was the design of all equipment with influence on the kiln process. In particular, the booster fan was designed after a detailed analysis to optimise the pressure drop of the circuit. This included parts of the system not directly related to the SCR system's operation. A detailed CFD analysis allowed a reduction of the pressure drop of the node, between the raw mill and the gas conditioning tower, leading to a global optimisation of plant operation.

A new pump skid had to be installed to optimise the ammonia pressure for the dosing system at the top of the preheater tower. This reduced the investment cost and avoided additional assembly time. The results show that after detailed process calculations, most of the ammonia storage and dosing systems are being reused.

The results and optimisations

The target of the project was to reach, using a SCR system, emissions levels lower than 200 mg/Nm^3 of NO_x and 30 mg/Nm^3 of NH_3 (daily average, dry gas, 10% oxygen) and respective half-hour averages for both constituents as mentioned before, without any adverse effects to the kiln process or to the quantity of waste co-incinerated. Due to a sophisticated control scheme developed by Dyckerhoff, the dosing of ammonia is handled in optimum conditions to reach the targets (Figure 9).

The ammonia consumption analysis shows a reduction of the specific consumption of the SCR system, compared with the previous SNCR system.

During the first months of operation, commissioning and process engineers made several adjustments to the automatic regulation algorithms and optimised equipment. The operation of the soot blowing system was tracked in order to improve efficacy and reliability and reduce compressed air consumption.

The system's power consumption is increased as a result of the need install a booster fan in order to overcome the SCR pressure drop and the compressed air station. That said, the high efficiency booster fan was designed to consume the least possible amount of energy. Moreover, the variable speed compressed air station allows for a power consumption reduction of the soot blowing system (compared to fixed speed compressors), by using less compressed air than usually required in the process. The total SCR system power consumption results are around 6.5 kWh/t of clinker at present.

Conclusions

Boldrocchi and Dyckerhoff's cooperation has led to the design of a complete High Dust SCR system, integrated with the Deuna plant's existing facilities, that achieves all objectives. The system's performance has been successful: the NO_x and NH_3 emissions are meeting legal allowed limits and ammonia and power consumption are at a minimum, putting Buzzi Unicem/Dyckerhoff's Deuna plant on the map for leading environmental practices. ■

About the authors

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L. Maiocchi is the Director of the Air Pollution Control Division of Boldrocchi Group. He started his career 25 years ago in the environmental field with particular dedication to engineering activities and innovative solutions in the air quality field. He is President of Boldrocchi France and Boldrocchi Egypt.