LOW NOx ROTARY KILN BURNER TECHNOLOGY :
DESIGN PRINCIPLES & CASE STUDY

By :

Max H. VACCARO
Sales Manager
PILLARD E.G.C.I, Marseilles, France
max.vaccaro@pillard.com

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ABSTRACT
In the coming years, numerous cement plants in USA could be forced to comply with tightening air emission regulations especially with regard to nitrogen oxides (NOx). The United States Environmental Protection Agency (USEPA) is currently considering Low NOx rotary kiln burners as a cost effective and efficient choice for NOx reduction in cement kilns. This paper will discuss the principles behind the design of low NOx kiln burner and will present data gathered from research on an industrially scaled cement kiln. Finally the results in NOx emission reduction by means of a low NOx burner application on a rotary cement kiln in Europe will be presented.

INTRODUCTION
The operating principle of low NOx burners is a stepwise combustion which delays the mixing and input of fuel and air at appropriate stages in order to achieve a controlled combustion process. This results in a fuel rich flame core and lower peak temperatures. Extensive experience relating to low NOx burners has been made available since the early 1970's from boiler furnace engineering. The first generation of low NOx burners applied to furnaces were using the basic principle of air staging (see figure 1).

Nowadays, the new generations of low NOx burners applied to heavy industrial furnaces not only use the technology of air staging but also utilize fuel staging technology using very specific fuel injection points which helps to reduce the NOx emissions even further.

HISTORIC BACKGROUND OF COAL FIRING ROTARY KILN BURNERS DEVELOPMENT
More than 30 years ago the first multi channel kiln burner for pulverized coal firing was introduced (see figure 2.).

In this burner, a channel feeding pulverized coal by means of a constant conveying air flow was located between two primary air channels for swirl air and axial air. The purpose of the interior swirl air component was to expand the pulverized fuel flow and stabilize the flame by generating an internal recirculation zone. In this manner it was possible to control the flame shape in conjunction with the constricting effect of the exterior axial air component. The basic principles of this burner were a low coal injection velocity in order to reduce wear and a low conveying air flow in order to keep additional primary air input (necessary for adjustment of flame shape) and thus total air input along the burner, as low as possible.

The design principle of this multi channel burner, which was generically called the “three channel burner”, has played a dominant role in the history of rotary kiln firing in the years following its development.
APPLICATION OF LOW NOX BURNER DESIGN TO ROTARY KILNS

In the meantime, increased environmental requirements in Europe made it necessary to search for better solutions for reduction of NOx emissions while maintaining or improving product quality and kiln operation. Experience gained from low NOx burner technology in boiler furnaces (using air staging principle) and also from hundreds of firing systems in rotary kilns, in conjunction with theoretical studies by the combustion research department of Braunschweig University in Germany, finally concluded with a complete revision of the burner tip geometry (see figure 3).

(Figure 3.)

Those revisions were:
- The pulverized fuel duct was relocated to the central part of the burner i.e. inside the swirl and axial air channels.
- For flame stabilization a kind of bluff - body, the flame stabilizer, was installed inside the coal channel. The purpose of the stabilizer, a concept from boiler burner technology, was to induce recirculation core eddies in order to guarantee proper stability of the flame root.
- The swirl and axial air channels were optimized by design measures, with respect to pressure drop, in order to convert the available pressure of the primary air supply to a maximum tip outlet velocity so as to maximize the momentum necessary for flame control while minimizing the primary air flow.
- The previously designed annular gap for the axial air channel was replaced by a number of slots. The purpose was to maintain a perfect concentricity of the axial air channel and to promote the introduction of recirculated combustion gases of high CO2 content into the flame root, thus reducing the free O2 content.
- An air guide ring was added to correct outflow direction of axial air component and thus prevent premature mixing of the fuel-/primary air mixture with hot secondary air.

An early low NOx burner prototype was installed in a German cement plant in 1989 and incorporated the following basic principles for reducing NOx formation:
- Proper flame stabilization by generation of a strong inner recirculation zone, promoting early ignition of the fuel into an oxygen deficient atmosphere.
- Concentration of fuel along the burner axis in order to prevent fuel particles leaving the main flame contour and burning at over - stoichiometric conditions in the hot secondary air atmosphere.
- Reduced primary air amount in comparison with previous burner designs. Approximately 8% to 10% of total combustion air requirement flows into the axial, radial, central and pulverized fuel channels compared to around 15% with a typical three channel burner.
- Improved burner tip aerodynamics and adjustable tip position which allows flame shaping with a minimum of primary air input and maximum outlet velocity as no primary air valves are used for primary air flow adjustment.
- More even heat distribution in order to reduce temperature peaks which are responsible for higher NOx formation and also for increased thermal stress on the refractory lining.

This burner showed significantly reduced NOX emissions without affecting process efficiency or product quality and initiated the path for further development.

“CEMFLAME” RESEARCH CONSORTIUM

In 1993, a European consortium of cement producers and associated research organizations was formed with the purpose of funding research on a scaled simulation of an
industrial cement kiln. This consortium was known as “CEMFLAME”. The first research program was proposed to study the influence of fuels and burner design on NOx generation.

Effect of fuel type:
During the experimental campaign, fuel type was observed to have a strong influence on the flame characteristics. Depending on the pulverized fuel characteristics (type, fineness...), a long coal jet could be visible or ignition of the coal close to the burner was observed. Ignition further downstream the furnace generally resulted in higher NOx levels when compared to early ignition at the burner tip.

Effect of burner design:
The highest NOx emissions were obtained from a mono channel burner design whatever the fuel type. Due to high axial momentum promoting high entraining of secondary air, the flame was igniting further downstream in the furnace, and at the point of ignition more air was entrained into the flame leading to high thermal NOx formation.
For the case of the generic three channel burner design, the effects of tangential momentum (radial air), resulted in the following: A slight reduction in NOx level was observed due to a part of the coal flow being entrained into the oxygen lean condition of the flame centerline. However, the overall entraining of the secondary air was enhanced due to an increased tangential momentum resulting in higher overall oxygen concentration at the point of ignition. Both effects were competing against each other, therefore results in terms of NOx reduction were not optimum.

Conclusions:
In view of the above observations, the influence of the pulverized coal channel location in comparison to the primary air channels (axial and radial) was proven to be of extreme importance because of its strong effect on the amount of coal being entrained in the local oxygen lean region of the burner. Hence, it was proven that best location for coal channel should be in the burner center, then surrounded by both primary air streams.
Also, it was demonstrated that the air distribution affects the local mixing in the near burner zone and the ignition point. Higher axial momentum (like for mono channel burner type) results in high secondary air entraining into the axial air stream. As a result, local mixing between the hot and oxygen rich secondary air flow and the outside of the coal jet is enhanced, thus promoting higher thermal NOx emissions.

Lastly, it was observed that the ignition point location and temperature was of major importance in NOx generation; the earlier the ignition point occurs the lower the NOx emission level.

CASE STUDY OF REDUCTION IN NOx EMISSION WITH A LOW NOx BURNER
In 1996 the European Community financed a research program entitled “NOx emissions from Cement Manufacture and Evaluation of Various Possibilities for NOx reduction in the Cement Industry”. A series of tests were performed in a cement plant, the aim of which was to demonstrate the potential reduction in NOx emissions through the optimization of the main kiln burner design without affecting clinker quality and production output but without increasing other pollutant emissions. For this purpose, a low NOx burner was tested in the SARCHÉ cement plant in Italy:

SARCHÉ plant, a 700 tpd LEPOL grate cement kiln, was originally equipped with an indirect fired mono channel type burner firing 100% petroleum coke and having a total primary air input of 10.5% of the total combustion air requirement (stoechiometric basis).

A multi channel low NOx burner design was installed to replace the mono channel burner and was commissioned in March 1996.

Commissioning phase:
Due to oversizing of the low NOx burner tip with regard to heat output (24 Gcal/hr instead of 16 Gcal/hr) a higher percentage of total primary air was found when compared with the original mono channel design (17.5% versus 10.5%). Notwithstanding the fact of higher primary air compared to the original mono channel burner, a NOx reduction of 28% at kiln inlet was obtained while keeping low CO and SO2 levels and a normal kiln shell temperature. However, a higher specific fuel consumption (830 Kcal/kg clinker versus 805 Kcal/kg clinker) was found, partially due to the high percentage of primary air and to a change in the burning zone.

First experimental campaign:
New settings were made to the burner in order to reduce the primary air amount as much as possible while keeping the existing burner tips. The total primary air input was reduced from 17.5% to 12.5%. This setting was maintained for some weeks and showed, with a good repeatability, an average of 45% NOx reduction from original mono channel burner.
The main goal of this experimental campaign was the optimization of the burner tip through an understanding of the effect of axial and radial flow rates in terms of axial momentum and swirl number. For this purpose it was decided to install continuous flow measuring devices on the axial and radial air channels. After installation of these flow measuring devices, new tests were performed to investigate the effect of a different primary air distribution and a higher primary air flow on the NOx emission level. This series of tests confirmed the fact that the burner tip was oversized and justified a revision of the tip design with smaller cross sections.

Second experimental campaign:
A new set of burner tips with smaller outlet sections was installed in June 1996 in order to further reduce the total primary air input to 11.4%. At that time a 54% NOx reduction was achieved at the kiln inlet, however, kiln operation problems arose. The kiln became unstable with a reduction in production and a significant increase in SO2 emissions. An immediate intervention was necessary in order to permit normal kiln operation without losing production capacity. A hybrid tip configuration was chosen using the swirler of the old tip. This tip geometry was maintained for one month giving better operational results, but the SO2 emissions were still significant and heat consumption of the kiln was not optimal. Moreover, a buildup on the axial air tip of the burner was observed. A kiln shutdown was necessary to clean the burner tip in order to avoid flame distortion. The cleaning of the axial tip resulted in a better kiln operation with a slight decrease in SO2 emission but for a limited time. However, after a few days the SO2 level became unacceptable because the axial air tip was partially plugged again.

Final burner tip design:
Several changes in burner tip design occurred between July and September 1996. The best compromise was found by using an increase in the axial outlet cross section while keeping the same number of slots to maintain tip concentricity. This design allowed the use of a higher primary air flow through the axial air channel and a thus better cooling of the axial air tip. The primary air input from axial, radial, central and pulverized fuel channels was increased to 13.6% of the total combustion air. Operation results were very satisfying with negligible SO2 emissions and a more stable kiln behavior. A slightly higher NOx emission was recorded but given the fact that SO2 emission had disappeared and that a more stable kiln behavior positively influenced production performance and clinker quality, this setting was adopted as the final one. It is to be noted that during this last period, the production was increased to 710tpd (+15.8%) and specific heat consumption was reduced to 800 ~ 805 Kcal/kg clinker while NOx emissions were reduced by 35% from those by original mono channel burner design.

Conclusion of the tests:
First, a multi channel low NOx kiln burner made according to Figure 3, by design itself clearly reduces the NOx emission when compared to a mono channel burner while keeping low CO and SO2 levels.

Also, the influence of primary air on NOx generation has been investigated, showing that the reduction in primary air positively influences NOx emission. However primary air reduction should be kept within certain limits in order to maintain a good and stable kiln operation, especially in the case of using high sulfur and low volatile content pulverized fuel such as petroleum coke.

Lastly, the geometrical feature of the burner is of extreme importance in order to avoid plugging problems that would eventually result in reduced performances.

### SEMI DIRECT FIRED LOW NOX BURNER TECHNOLOGY

Generally, low NOx burners are used in conjunction with an indirect firing system that allows a reduction in total primary air to the kiln in comparison to a direct firing system. The benefits given by an indirect firing system are well known but in some cases conversion to indirect firing can hardly be justified from an economical point of view. Therefore the advantages of using of a modern multi channel low NOx burner can be missed.

However, it is to be noted that installation of a modern low NOx burner technology on a direct fired kiln is possible.
With a few modifications to the coal milling circuit it is possible to convert the firing system to semi direct i.e. by adding a cyclone on the primary air stream coming from the coal mill and redirecting this primary air to a multi channel low NOx type burner. In this case, the primary air to the burner is indeed higher than with an indirect firing, however the effect of flame stability, and combustion staging, as demonstrated before, may effectively contribute to a reduction in NOx emissions.

This type of semi direct firing system was commissioned in 2001 on two long wet kilns at LOGANSPORT plant in Indiana. NOx data after installation of the low NOx burners are not yet available at this plant. However kiln stability and clinker quality have been improved since installation of these low NOx burners. According to users, the clinker reduced iron content is lower and average clinker free lime have been increased. Finally, there is no more problem with nose ash ring formation since installation of the new burners.

Experience gained from the LOGANSPORT project has lead to a new generation of semi direct firing systems (see figure 4) which aim to reduce NOx by installing a low NOx kiln burner design and additionally by reducing the primary air inside the main flame core.

(Figure 4.)

In this type of semi direct firing system the primary air going into the main flame is limited to the amount necessary to provide the required momentum for flame control. The primary air in excess (called “additional secondary air”), i.e. that which is not necessary for flame control, is evacuated inside the kiln hood before the burner tip by means of an additional channel surrounding the burner. In this way, this “additional secondary air” does not enter the main flame which can now fire with a lower primary air amount leading to reduced NOx emissions.

CONCLUSION
The above paper has discussed the design principles of low NOx burners and shown how NOx emissions can be reduced at the kiln inlet by the means of such burners.

The theoretical studies from “CEMFLAME” research group have proven that it is possible to achieve drastic NOx emission reductions by burner design. Geometrical feature of the burner and mostly, the location of coal channel in comparison to the primary air channels are of extreme importance.

Additionally, actual testing in SARCHE cement plant has demonstrated that low NOx kiln burners can, with a good repeatability and over a long period of time, reduce the NOx emissions at kiln inlet while maintaining clinker quality, heat consumption and kiln stability, and without increasing SO2 and CO emissions.

Still experience and research in the field of NOx reduction from the kiln burner standpoint is progressing. In partnership with ITALCEMENTI a new campaign of tests will be performed shortly in Europe with the goal of looking at additional design features to further reduce NOx from the current levels obtainable today with a “standard” low NOx type burner while maintaining or improving clinker quality and production performance. The new burner designs are subject to several patents:

- US patent 6293208 by: R.Guiot/L.Russo/J.C.Gauthier/J.C.Pillard
- US patent 6315551 by: P.Salzsieder/G.Endres/R.Guiot
- European patent 0421903 by: W.Collenbush
- European patent 0926435 by: J.C.Pillard/J.C.Gauthier/J.Pizant
- European patent 0967434 by: P.Salzsieder/G.Endres/R.Guiot
- European patent 1045203 by: R.Guiot/R.Asdiguian