Reheating furnaces with low NOx emissions

Tenova LOI ITALIMPIANTI's FlexyTech® reheat furnaces have been further developed with new burners to achieve extremely low levels of NOx emissions of 40 ppm @ 3% O_2 in dry flue gases, coupled with improved energy efficiency.

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In recent years much effort has been devoted to the environmental impact and control of pollutant emissions in steel reheating furnaces by increasing furnace energy efficiency and the development of combustion systems. Strong environmental legislation has led US and Japanese manufacturers to develop a new generation of low NOx burners and recently, following fundamental research in Europe, burners based on this technology are applied in relative small scale (up to 300kW), although no European burner manufacturer could offer high thermal capacity (up to 5MW) very low NOx burners in spite of market requirements.

In the past, the main obstacle to reach both objectives simultaneously had been the conflict between air preheating, the most widely used measure to increase furnace efficiency, and the resulting increase in the NOx emissions. Thermal NOx formation, the main NOx source in natural gas combustion, is controlled by flame temperature, oxygen concentration in the reaction zone, and by residence time of the combustion products in the high temperature zone of the flame.

Staged combustion (air and fuel), flue gas recirculation (FGR) and partially premixed combustion are techniques used in the design of very low NOx natural gas burners in several industrial sectors (power, petro-chemical, glass, ceramic, cement). However, recent developments in the basic understanding of flameless technology, has opened new perspectives for innovative firing technology in furnaces. Today, therefore, it is possible to provide significant emission reduction coupled with energy savings.

Tenova LOI ITALIMPIANTI`s FlexyTech® furnaces *(see Fig.1)* are engineered in order to assure high in-service performance (efficiency, thermal quality and low environmental impact) close to their reference condition. The principal fields of innovation are new burners, new rapid and accurate combustion control techniques and computer modelling for off-line simulation of different design solutions and for best online furnace regulation (level 2).

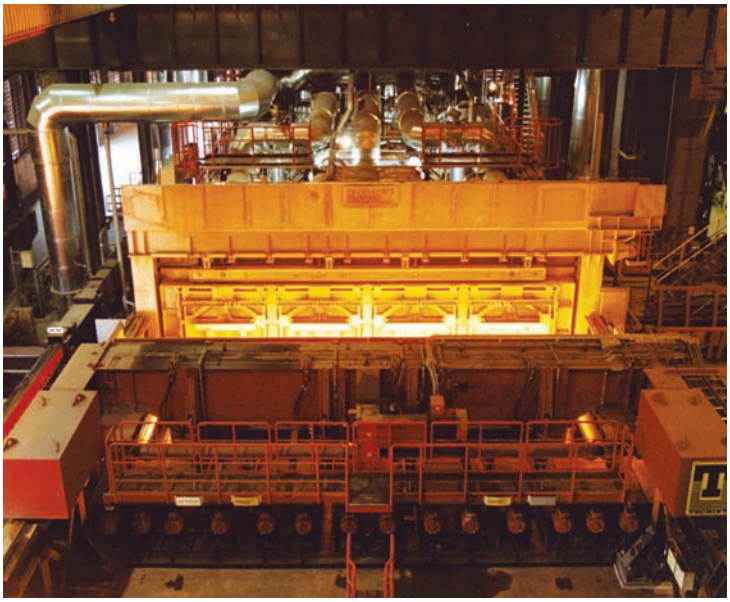

Fig.1 **Low NOx, high efficient FlexyTech furnace**

FLEXYTECH® BURNERS

R&D project objectives As a result of US market requirements for a very low NOx burner, we started a research program in 2002 in order to significantly lower NOx emissions compared to the previous generation of Tenova LOI ITALIMPIANTI low NOx high speed burners.

The main goals of FlexyTech® burner R&D projects were:

- To investigate innovative combustion techniques for reheating processes
- To develop new components and control strategy for reheating furnaces
- To transfer combustion technology from R&D to industrial application

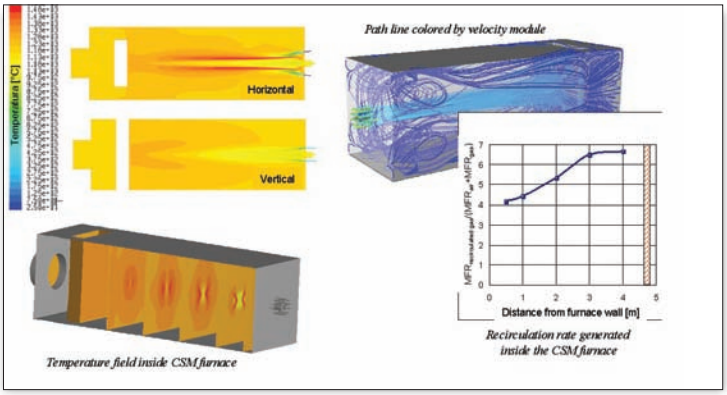

Fig.2 **Examples of CFD mathematical modelling**

In doing that, a design process has been set-up involving mathematical modelling, semi-industrial testing, industrial trials and industrial applications.

CSM combustion facility All the semi-industrial scale tests have been performed at the CSM Combustion Laboratory in Dalmine where a modular furnace is available. Its main characteristics are:

- Cross section 2m x 2m
- Variable length (3m, 4.5m, 6m, 7m)
- Thermal input up to 2.5MW
- Water cooled lances to control process temperature
- Air preheating up to 600°C

The combustion chamber temperature as well as the flue gas composition can be monitored while the turn-down conditions typical of an industrial furnace can be reproduced.

Mathematical modelling

Mathematical modelling of the new burners/furnace system has been performed during the different phases of the project by testing a conceptual design before getting to a prototype stage and to provide a reliable method of scaling existing designs to both larger and smaller applications *(see Fig. 2)*. Combustion was simulated using FLUENT™ code, paying particular attention to the selection of a proper turbulence model in order to overcome the `round-jet/planar-jet anomaly` by adopting the Wilcox k-Ω turbulence model after proper validation.

Burner development Since the early 1960s Tenova LOI ITALIMPIANTI (former Italimpianti) has continually developed new burners to comply with the appropriate national standards concerning NOx emission and has always installed its own burners. Todate, many thousands have been installed. The R&D program consisted of two phases; development of the TSN burner followed by the TSX burner.

TSN burner In the first phase the target values for NOx emissions were fixed at 65ppm @ 3% O_2 in dry flue gases, considering a reheating furnace operating with zone temperature set point between 1150°C and 1250°C and with preheated air fixed at 450°C.

The starting point for the TSN burner development were the results of the TSD Double Air burner. These experiences confirmed that a standard low NOx baffle geometry was not suitable both for burner ignition and for furnace start up, so a burner which couples start up function (pilot) and very low NOx operation (high impulse jet) was designed. The geometry was studied with the aim of delaying, as much as possible, fuel and air mixing. In such way oxygen dilution with waste gas can take place and the temperature peak of a traditional burner is reduced, with a positive effect on NOx formation even if a flame is present. A burner was designed with internal air for ignition and first heating of the furnace and external air for low NOx firing. Very low NOx firing can take place only if the furnace temperature is higher than the auto-ignition limit of the fuel. If the furnace temperature drops below this value, safety logic switches operation from very low NOx firing to ignition firing.

Several conditions were investigated during the development, spanning furnace temperatures in the range 1150 - 1250°C, different combustion air temperatures and air excess. Some results of extensive tests on the prototype TSN burner are reported in *figure 3* where NOx versus air excess % is plotted at different furnace temperatures.

TSX burner Based on the experience gained with the TSN project, Tenova LOI ITALIMPIANTI started the more ambitious TSX project in 2003, with the goal of obtaining a burner with the following characteristics:

- NOx emissions below 40ppm @ 3% O_2 in dry flue gases
- Ultra low CO emissions (below 5ppm)
- No valves on hot air for air staging
- Least excess air operations for maximum fuel efficiency
- NOx emissions not affected by air temperature
- NOx emissions not dependent on turn-down
- Air preheating up to 550°C

All these goals were reached. Burner development has been based on flameless combustion technology associated with high combustion air preheat. The burner was designed in order to operate efficiently both in flame (pilot) and flameless mode (very low NOx) thus

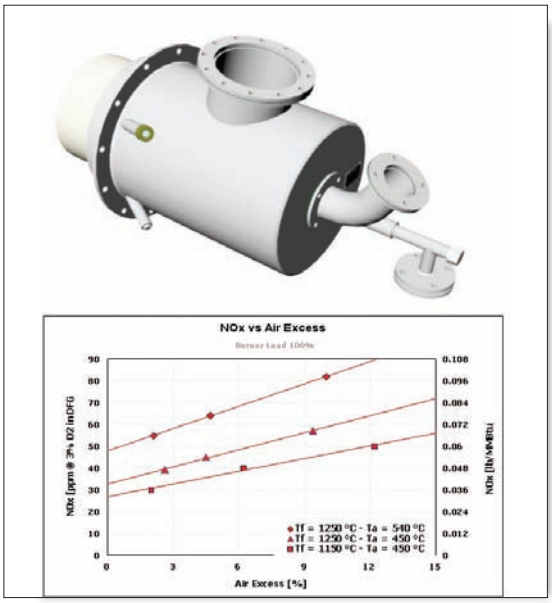

Fig.3 **TSN burner and plot of NOx emissions versus temperature and excess air**

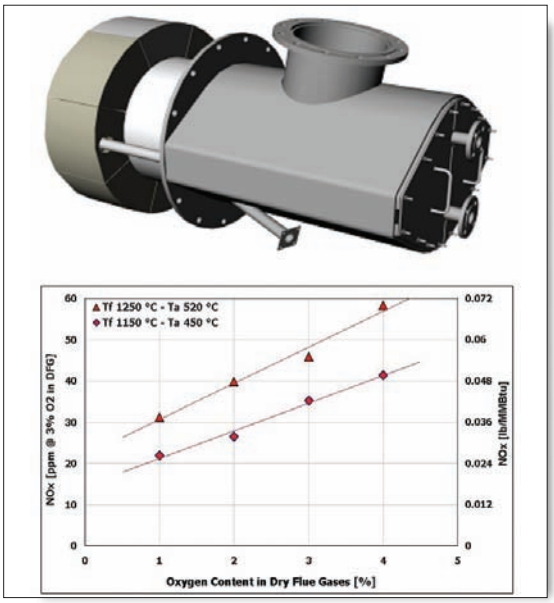

Fig.4 **TSX burner and plot of NOx emissions versus temperature and excess air**

achieving low NOx emissions typical of flameless operation and additional advantages such as heat transfer uniformity with a relevant improvement of the charge temperature uniformity, noise abatement and high flexibility. Some results of extensive tests on the prototype 1.2 MW TSX natural gas burner, with air preheated at 450°C and 520°C, are shown in *figure 4.*

TSX burners achieve lower NOx emissions than TSN burners even with high excess air. Trials on a test rig at CSM confirmed that emissions are essentially not dependent on preheated air temperature, both with a `cold` furnace (1150°C) and a `hot` furnace (1250°C) with flameless combustion.

INDUSTRIAL APPLICATIONS OF FLEXYTECH® BURNERS

The encouraging results achieved during the R&D projects have been confirmed and further improved in industrial installations. Two examples of furnaces equipped with the new burners are considered; North American Stainless (NAS) and Rocky Mountain.

North American Stainless The 60 t/h walking beam furnace (WBF) *(see Fig.5)* is equipped with 24 TSN burners of various thermal capacities. The guaranteed value of NOx emissions was fixed at 0.075 lbs/MMBtu (~63 ppm @ 3% O_2 in dry waste gases). The value of NOx emissions measured on the furnace *(see Fig.6)* by the Kentucky Division of Air Quality were far below the guaranteed value and were obtained with a relatively low heating temperature of 1100°C. The reduction of ▷

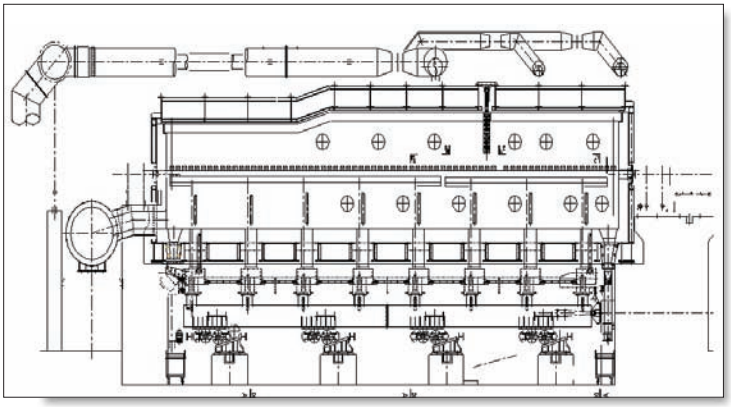

Fig.5 **NAS furnace design schematic**

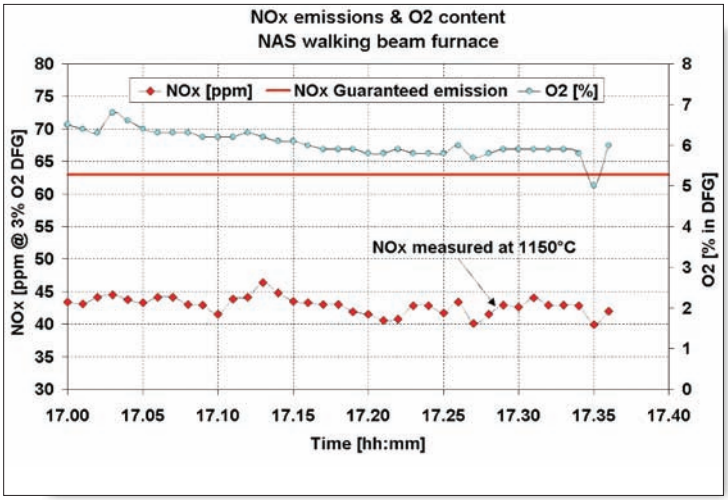

Fig.6 **NOx emissions at North American Stainless, TSN burners**

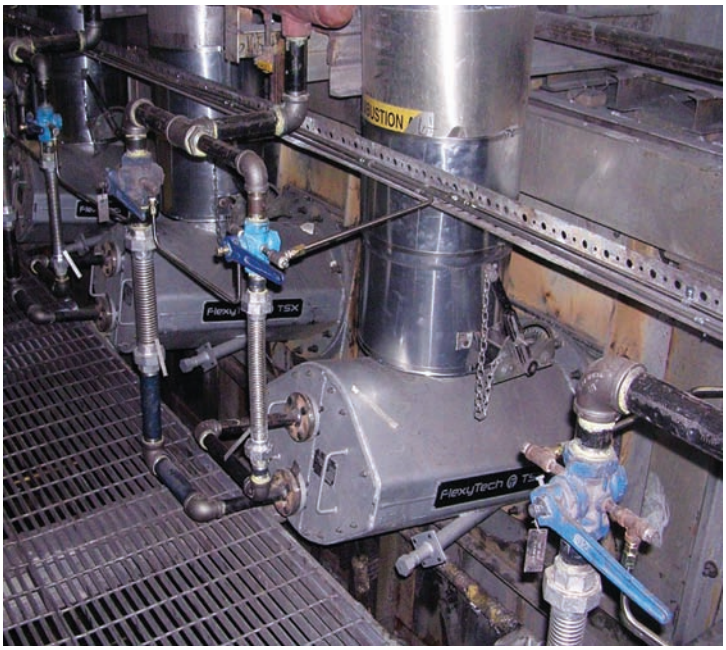

Fig.7 **TSX burners at Rocky Mountain**

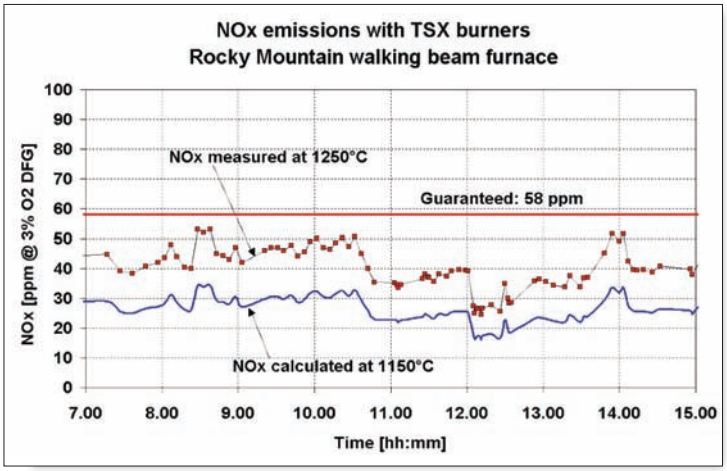

Fig.8 **Measured and calculated NOx emissions at Rocky Mountain,TSX burners**

NOx emissions on the WBF compared with the test furnace measurements can be attributed also to the higher recirculation rate achiveable on bigger furnaces where the combustion environment is less constrained than on the test rig. Under the same conditions a furnace equipped with TSX burners could achieve 40% lower emissions than with TSN.

Rocky Mountain The Steel Bar & Rod Mill 125 t/h WBF is equipped with 26 TSX burners of various thermal capacities installed in the heating zones and 27 TRN roof burners in the soaking zone *(see Fig.7)*. In this case the NOx emission limit to be guaranteed was 0.070 lbs/MMBtu (~58ppm @ 3% O_2 in dry waste gases).

Several field tests carried out during the commissioning phase were also confirmed by the Environmental Authority of Colorado which demonstrated very low NOx emissions as reported in *figure 8*. Very low NOx emissions which were achieved throughout the whole turn-down range never affected the flexibility of the furnace operations: in every working condition, furnace emissions were below guaranteed limits. Measured NOx emissions are achieved with furnace a temperature of 1250°C. In order to compare the performances of TSX and TSN burners a theoretical curve of NOx emissions at 1150°C was calculated. It should be considered that in this case the NOx value measured is affected by the presence of the roof burners whose emissions are normally higher than side burners.

The Rocky Mountain Project was realised by Core Furnace Systems, a Tenova licensee company.

CONCLUSIONS

Tenova LOI ITALIMPIANTI`s R&D programme which commenced in 2002, has led to a new family of very low NOx burners called FlexyTech® TSX, which achieve the best available technology limit of 40ppm NOx emissions. A number of furnaces with this technology have been built. Furthermore, two industrial walking beam furnaces have been fitted with 5MW TSX flameless burners; at. Arcelor Espana in Aviles (coke oven gas) and Hylsa in Mexico (natural gas). A 6.5MW TSX flameless burner for natural gas has also been developed, but not yet installed.

The R&D project is still ongoing and it will concern regenerative and roof burners for different kinds of fuels.

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The original version of this paper was first published in Steel Times International, Sept 2005