MINIMIZING NOx EMISSIONS FROM REHEATING FURNACES

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1. ABSTRACT

This paper presents an overview of the main results of the work carried out with a financial grant from the Research Fund for Coal and Steel (RFCS) of the European Community in the frame of project “Minimizing NOx emissions from reheating furnaces” or NOXRF.

2. INTRODUCTION

The request for reducing pollutant emissions and improving production rates for different types of industrial furnaces are putting more stringent requirements on furnace manufacturers and burner suppliers. These requirements include, for example, reduced pollutants emissions, reduced energy consumption, the possibility of reduced equipment size in industrial installations or increased production rate. In the past the main obstacle to reach, at the same time, more than one of these goals had been the conflict between air preheating, the most widely used measure to increase furnaces efficiency, and the resulting increase in the NOx emissions. Therefore focus of NOXRF project has been on primary NOx reduction technology such as flameless combustion technique [1-2] and the combination of staged and separated jets injection of fuel and oxidant [3,4].

3. BURNERS WITH AIR PREHEATED BY CENTRAL RECUPERATOR

To provide guidelines for primary NOx abatement in the steel reheating furnace, tests were made of several burners, representative of different combustion technologies conventionally used in the furnaces equipped with central recuperators or technology which became available during the NOXRF project. The NOx emissions of large size burner (>1000kW) have been measured in the CSM Combustion Station Modular Furnace (2m x 2m x 7.5m) burning natural gas (NG) while medium size burners (~500kW) have been tested in the BFI pilot plant furnace (1m x 1m x 8 m) for NG and Coke Oven Gas (COG) and in the MEFOS pilot furnace (1.3m x 1m x 3.1m) for propane. In particular BFI tested a traditional flame burner (Hennig – 320kW) and CSM investigated burners that operate with dilute combustion air obtained by high impulse air jets (Internal Flue Gas Recirculation), such as TENOVA TSN (1.5MW) and Hauck TRIOX 2008 (1MW). Flameless combustion regime of TENOVA TSX-2MW and VTS-NFK HRS-300kW burners has been characterised by CSM and MEFOS.

3.1. Natural gas and propane

For natural gas and propane combustion the series of trials clearly indicate that, for reheating furnaces equipped with air preheaters, the flameless combustion is presently the Best Available Technology (BAT) for primary NOx reduction allowing a decrease of 80% in NOx emission respect to traditional flame burners through the entire O_2 test range (fig. 1).

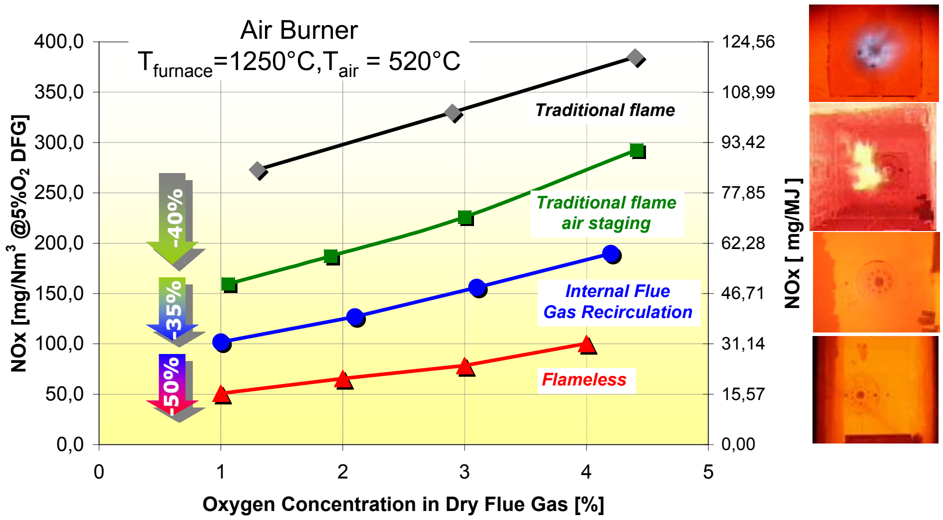

Fig. 1. NOx emissions of side burner for reheating furnaces with central recuperator as measured in NOXRF

3.2. Coke Oven Gas

Tests of the Hennig SBLN burner with COG has been made at BFI in order to investigate the influence of this kind of fuel on NOx. Fig. 3 shows the comparison of the burner emission levels with COG and NG. For an air temperature of 450°C the emissions of COG are about 133 mg/m ^{3} higher. The higher flame velocity (higher flame temperature) and chemically combined nitrogen in the COG are responsible of higher NOx emissions respect of NG.

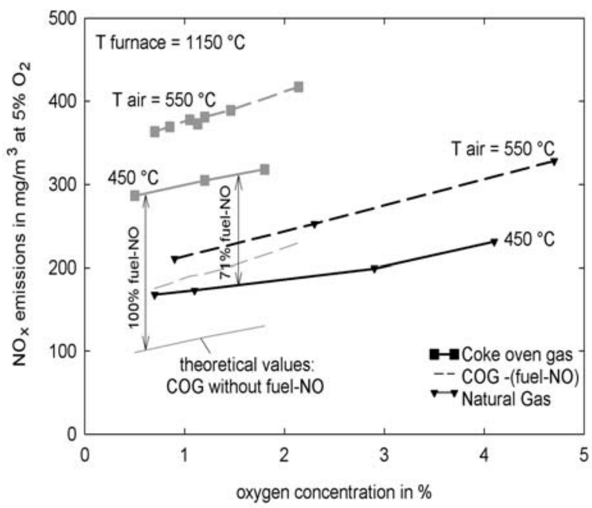

Fig. 3. Comparison of NOx emissions for the Hennig SBLN burner tested with COG and NG

Taking into account the higher NOx formation due to the higher flame temperature the conversion of chemically combined nitrogen in the COG has to be lower than 71%. For 550°C air temperature a maximal conversion of approximately 88% can be calculated.

4. REGENERATIVE BURNER

Commercial regenerative burner, named FBB TriX100, has been tested at a nominal firing power (600kW calculated as the flow rate of fuel multiply by lower heating value of the fuel) for two different furnace temperatures (1250°C and 1150°C). The tests investigated the effect of different fuels as NG (BFI and CSM) and COG (BFI) together with the effect of the combustion chamber geometry and size. The NOx emissions reported in fig. 4 has been measured both at the exit of the regenerator and after the shutting flaps (by ISQ) at the CSM Modular furnace with the pair of burners mounted on the same furnace wall. The higher level of NOx emissions than for BAT side burners (fig. 1) is not justifiable only by higher combustion air temperatures. The main reason must be found in the combustion regime: the FBB regenerative burner produces a stable and attached flame in all the operational conditions.

Concerning the new ceramic foam regenerator system that equips the burner, high efficiency of air preheating has been observed: with higher R the air temperature is 100°C lower than the furnace temperature. This produces a furnace efficiency (1) of up to 80% with the pressure losses that range from 180 to 300mmH_2O as a function of the flow rate (750 to 950 Nm^3/h respectively).

$$\varepsilon_{furnace} = (Q_{NG} - Q_{flue\ gas}(stack + regenerator) - Q_{losses})/Q_{NG} \quad (1)$$

where $Q_{losses} = 5\% Q_{NG}$

The measured values are between the data usually measured for honeycomb and balls-type ceramic regenerators [5].

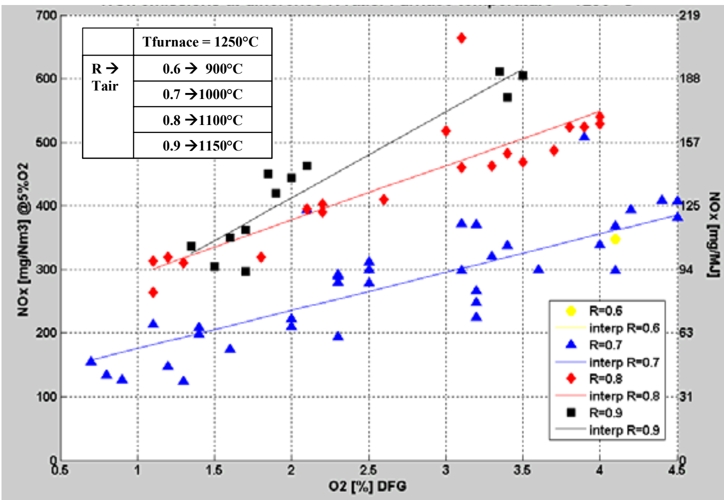

Fig. 4. NOx emissions for FBB TriX 100/NG at various R ratios with a $T_{furnace}$ 1250°C

5. OXYFUEL BURNER

NOx emissions and the performance of reheating furnace equipped with oxyfuel combustion system have been investigated in two series of trials using AirLiquide oxy-burner, named ALROLL-S. The burner utilizes a combination of staged and separated jet injections of the fuel and the oxygen to give low NOx. The ALROLL-S burner was tested firing NG and COG in the experimental furnace at BFI and propane in the WBF at MEFOS. Results of tests at BFI are reported in [4,6]. The NO_x levels has been under 12 mg/MJ with NG and under 25 mg/MJ with COG for all the examined cases. The higher NO_x emissions with COG versus NG were anticipated due to the nitrogen content of the fuel.

Fig. 5 shows clearly the influence of the charge and discharge of slabs during the MEFOS

WBF tests, thus the opening and closing of the furnace doors, with the associated air leakage in to the furnace. During stable operation with the furnace doors closed the NO_x levels reached 9 mg/MJ.

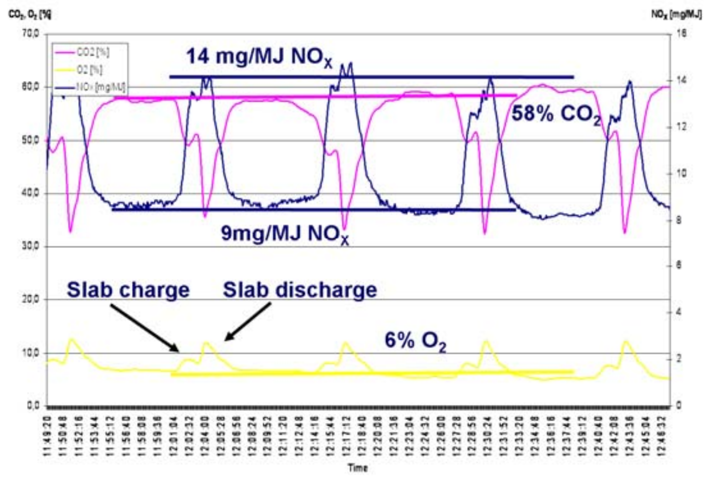

Fig. 5. NOx, CO_2 and O_2 in the flue gases sampling during oxyfuel trial in the MEFOS WBF

The problem of air infiltration was solved by increasing the furnace pressure and using a frequency controller for the exhaust fan, so more advanced solutions to the problem were not required. The reheating curves of the slab during the test in the MEFOS WBF equipped with different combustion system and the scale losses for three different steel grades were monitored as well in the project. Details results of these activities has been already published in [4].

6. NO_x PREDICTION

6.1. CFD burner modeling

FLUENT™ code has been used for simulating the combustion process by BFI, CSM, LABEIN and MEFOS for different burners types, size and fuels. Different approaches (turbulence and combustion models) have also been used as reported in [7].

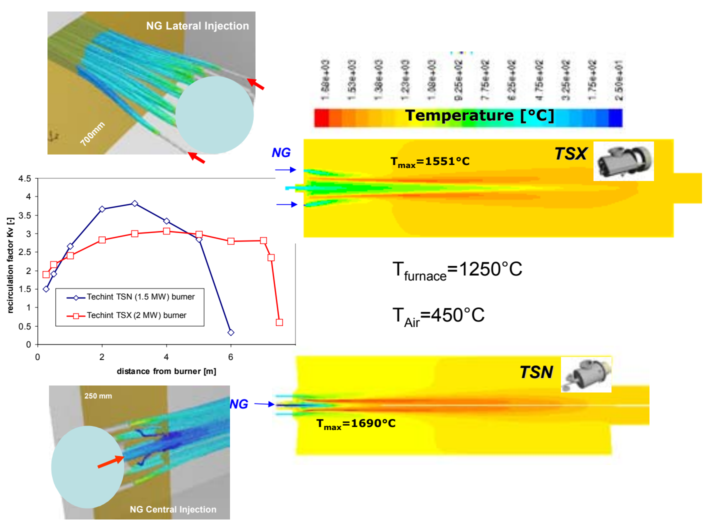

Fig. 6. Staged burner (TSN) vs. lateral gas/air staged burner (TSX) behavior

The simulations of IFGR and flameless air/natural gas burners (fig. 6) performed confirm that the maximum value of the temperature in the furnace (Tmax) is significantly lower than the adiabatic flame temperature of a air/CH_4 mixture with preheated air at 450°C (2174°C). This effect is due to the flue gas recirculation generated by burner jets that produce the dilution of comburent (air or oxygen) in the furnace and by the design of air and natural gas injections that allows the mixing at a distance from the burner tip at which the comburent is diluted and the fuel is partially pre-mixed.
Calculation of thermal and prompt NOx formation has been done by CSM and MEFOS using FLUENT NOx post-processor. Comparison between calculated and measured NOx confirms the limitation of FLUENT NOx model capability in case of diluted combustion regime: NOx variation trends can be predicted but an accurate quantitative value cannot be expected. To overcome this limitation a relation between temperature peak obtained by CFD simulations and NOx measured during the experimental trials has been developed (fig. 7).

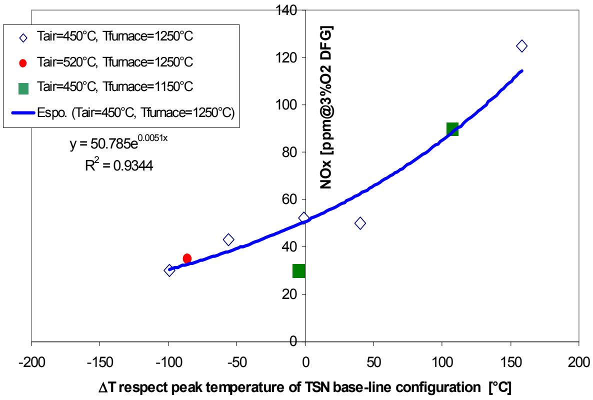

Fig. 7. NOx emission for TSN and TSX burner vs. peak flame temperature variation

6.2. Generalized model predicting NOx

TENOVA, in cooperation with the DIBE (Dipartimento di Biofisica ed Elettronica) of the University of Genova, developed and tested an empirical model (NANOx) for prediction of NOx emission. This was accomplished using neural networks [8,9] which were trained on NOx data from reheating furnaces (380 t/h WBF of TKS at Duisburg Beeckerwerth-Germany). The scatter plots (fig. 8) give the predicted value of NOx (on the *y*-axis) versus the actual NOx value (on the x-axis) and confirm the effectiveness of the neural-based approach.

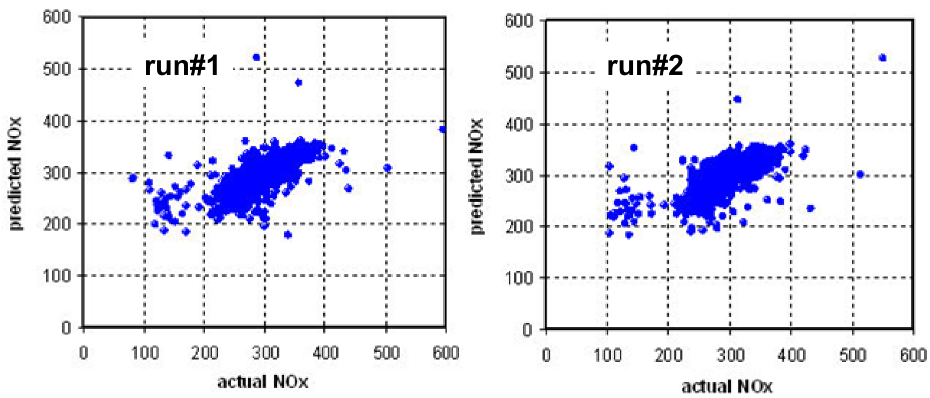

Fig. 8 - Estimated NOx values (mg/Nm^3) versus actual values for reheating furnace with central recuparator

7. Conclusions

Primary NOx reduction with low NOx burners can be considered the Best Available Technology (BAT) for steel reheating furnaces. In fact, the results of testing flameless low NOx burners for high temperature air combustion and separated jets injection of fuel and oxidant for oxyfuel combustion indicated that much lower NOx emissions are possible than with traditional flame burners. This offers to the steel industry NOx reduction methods in the furnace with low operating costs and remove the constrains for further development of a new generation of reheating furnace with high efficiency and low emissions. This is true for combustion system that use air preheating while for oxyfuel combustion the limit of NOx emissions, if expressed in $mgNOx/Nm^3$ by legislation, still remains a potential a problem.
The representativeness of the NOx measurement on the pilot scale plant for a single burner with a size of typical industrial installations (1-2MW) has been demonstrated by the comparison with the NOx emission obtained in the industrial furnaces built by TENOVA during with burners tested in the NOXRF project. Taking this into account, the results of the tests performed in the NOXRF project could be considered a reference data base for burners suppliers to benchmark their own products with presently BAT and by steel mills to select the NOx reduction technology that better fits with specific operation constrains and legislation limits both for the Greenfield projects and the revamping reheating furnaces.
In spite of some difference between the modelling and the measurements the results obtained in the project indicated that CFD can be used an engineering tool. However further activity to set-up and validate improved simulation models is required if the goal of direct NOx prediction has to be perused for flameless/diluted combustion regime. Modelling based on neutral networks, when properly trained, has shown a big potential for application at real time prediction of NOx emissions from reheating furnaces.

8. REFERENCES

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9. ACKNOWLEDGEMENT

This work was carried out with a financial grant from the Research Fund for Coal and Steel of the European Community. The authors thank the M.Daneri , C.Mori (TENOVA), B.Kaufmann (VAS), R.Tsiava (AirLiquide), and U.Zanusso (CSM), for the synergic collaboration within the project.