

# Numerical modelling of retrofitting an industrial boiler type OP-230 for predicting NOx reduction

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**Abstract.** This study focuses on the indirect co-firing CFD simulations of reductions in NOx emissions relative to the coal combustion. For the given biomass-derived syngas composition and 15% syngas heat input, two arrangements of nozzles dedicated to the syngas injection into the furnace of an older PC-fired boiler of type OP-230 with low-emission burners on the front wall were chosen to investigate the impact of their location on the reduction in NOx emissions. It was shown that the highest reduction achieved by means of the improvement of the air staging via the dual-fuel technique can reach up to 40% (Case 1: nozzles at the elevation of the bottom row of burners) and up to 32% (Case 2: nozzles above the upper level of the burners). The modelling results also showed that one can meet the requirements for co-firing of coal with waste derived syngas. The boiler can be retrofitted for the fulfilment of the prospective environmental protection regulations relating to levels of NOx emissions by combining the described technology with SNCR methods. It is also very important that the indirect co-firing enables reduction of carbon dioxide emissions proportionally to the syngas heat input.

## 1 Introduction

The direct and indirect biomass co-firing with coal are widely regarded as environmentally friendly technologies that can provide the commonly known benefits although they also have their disadvantages [1-3]. This study is conducted to determine whether a PC-fired boiler of type OP-230 with low-emission burners on the front wall can be effectively retrofitted via indirect biomass co-firing for the fulfilment of the prospective environmental protection regulations relating to levels of NOx emissions. The problem is of modifying the standard air staging technique, originally adapted for lowering NOx emissions slightly below 400 mg/Nm<sup>3</sup>, by biomass-derived syngas injection above or below the existing coal burners into the furnace through dedicated nozzles offering the largest flexibility in volumetric flow rate. This solution leads to the improvement of the air staging via the dual-fuel technique and its integration with low-NOx coal burners relative to the combustion of coal. The expected reduction in NOx emissions depends on arrangement of syngas nozzles, syngas composition and heat input replacement. The last factor determines the amount of avoided CO<sub>2</sub> emissions. The various attractive ways to modify low-NOx emission burners and the air distribution with the use of OFA, ROPA and SOFA nozzles may be found in [4-5]. The overview of NOx reduction technology is also done e.g. in [6-7]. Experiences with the commercial implementation of indirect co-firing technology were acquired mainly in

Finland (the Kymijärvi PC-fired CHP plant, Kymijärvi II power plant and the Vaskiluodon Voima plant in Vaasa) but also in Austria (the Zeltweg PC-fired power plant), Belgium (the installation at Ruien) and the Netherlands (the installation at Geertruidenberg) [3,8-9]. A large part of currently conducted research is focused on co-firing simulations with help of ANSYS Fluent CFD software [10] and other CFD software packages [11]. For example, the detailed numerical results for several options of co-firing the paper rejects syngas in a coal-fired boiler were reported in [11]. They are focused on the NOx and CO emissions and furnace LOI depending on syngas heat input and furnace stoichiometry. The highest NOx reduction of 46% relative to the coal combustion corresponded to 23% heat replacement. The simulations of the indirect biomass co-firing in a 600MW tangential PC-fired boiler with 14% heat input injection through the lowest layer burner conducted in [12] showed first of all that NOx emission can be reduced about 50-70% relative to the baseline case (no syngas). The results of similar simulations of co-firing the sewage sludge syngas in a PC-fired OP-650 boiler are given in [13]. The technical feasibility of co-firing biodegradable waste-derived LCV syngas as much as 10, 20 and 40% by heat input with coal in a 230t/h dual PC-gas fired boiler was investigated in [14]. Examining two extreme calorific values, it was discovered that the higher the syngas heat content, the greater coal substitution without the serious impact on boiler operation. The results of above studies give only some

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idea of the magnitude of NO<sub>x</sub> reduction relative to the baseline achieved under indirect co-firing different syngas with coal in selected PC-fired boilers. Therefore, for a given boiler and a type of coal and syngas, the reduction in NO<sub>x</sub> emissions cannot be predicted a priori from known hitherto data. It can be determined through proper research. This justifies the use of our own numerical simulations to conduct the evaluation of reductions in NO<sub>x</sub> concentrations in the furnace of a PC-fired boiler of type OP-230 with low-emission burners on the front wall. The comparison of the results obtained with the prospective standards of NO<sub>x</sub> emissions will answer the question formulated above. Simultaneously, it will turn out whether the syngas derived from agro biomass and fuels from waste containing such troublesome components as chlorine and alkali can be co-fired with coal.

## 2 Formulation of the problem

The basic data of the boiler are as follows: size - 8m×26.7m×8.66m, coal consumption B<sub>c</sub>=8.242kg/s, primary and secondary air volume flow rate (and temperature) - 14.48 and 25.96Nm<sup>3</sup>/s (378 and 603 K), respectively. The secondary air swirl is in line with the burner manufacturer recommendations. The boiler is equipped with (i) eight low-emission burners located at three levels on the front wall and characterized by the concentric dust nozzle supplying a fuel-dust-air mixture into the dust separator in which the mixture is divided into independent streams with alternately high and low concentration of dust coal favouring the formation of a reduction zone; (ii) twelve OFA nozzles installed on both opposite walls; and (iii) two bottom air nozzles located on the side walls in the region near the bottom of the main burners. The air staging system with OFA nozzles ensures complete combustion. The amount of air supplied to the boiler is controlled by monitoring flue gas oxygen level at the outlet from the furnace.

**Table 1.** Basic properties of coal

Item	Value
<b>Proximate analysis [wt%]</b>	
Moisture	12.4
Volatile matter	22.5
Fixed carbon	52.5
Ash	12.6
<b>Ultimate analysis [wt%] DAF</b>	
Carbon	80.77
Hydrogen	5.87
Oxygen	10.93
Nitrogen	1.73
Sulfur	0.29
Chlorine	0.40
LHV [MJ/kg]	23.44

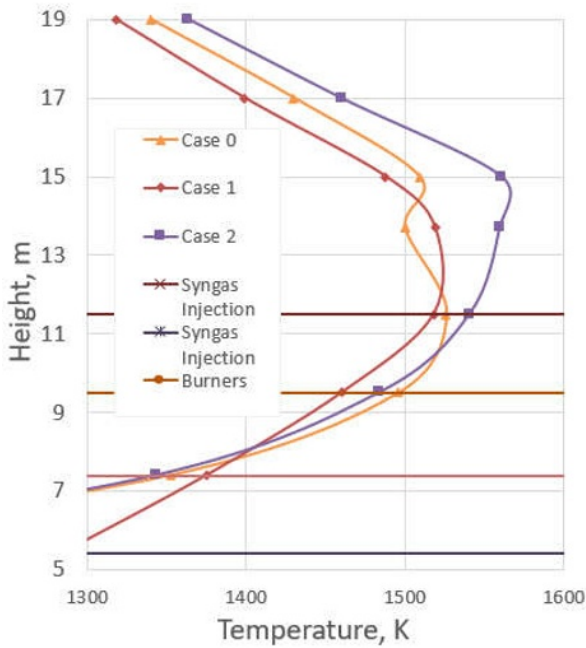
**Table 2.** Composition of co-fuel [15] (standard temperature 20°C and pressure 1013hPa)

<b>Components [%mol]</b>	
Item	Value
CO <sub>2</sub>	22.93
CH <sub>4</sub>	9.27
CO	30.91
H <sub>2</sub>	36.89
LHV [MJ/kg]	11.97

For the 100% boiler load, six of eight available burners were active in our simulations. The necessary settings were fixed according to the Fluent packet documentation. The mesh system consists of 990 000 polyhedral cells. The hybrid Finite-Rate/Eddy-Dissipation model [10] was used to describe the combustion of coal and the co-firing process. The kinetic data are taken from [15-16]. The standard k-ε turbulence model enables the turbulent Reynolds equations to be closed. The Discrete Ordinates radiation model was used to simulate the radiation heat transfer. The combustion of coal is the baseline case (Case 0). The coal chemical composition is given in Table 1. We limit ourselves to study of co-firing one syngas whose chemical composition is presented in Table 2. In order to evaluate its impact on the reduction in NO<sub>x</sub> emissions, two arrangements of nozzles were simulated: (i) four nozzles at the elevation of the bottom row of burners (Case 1); and (ii) two nozzles on the front wall above the upper level of the burners (Case 2). These two simulations were conducted under the assumption that the heat replacement is equal to 15%. The co-fuel was fed to the furnace through nozzles of a diameter providing a gas velocity within 25 to 30m/s to ensure gas supply to the center of the combustion chamber. The indicated two arrangements of nozzles resulted in different oxygen concentration and temperature profile in the furnace. The results achieved are compared with those for the baseline (Case 0). The gas supply was accompanied by a change of air distribution in the furnace. The reduced amount of combusted coal dust allowed to move the air from the burners to the OFA nozzles. To simplify a comparative analysis it was assumed that the syngas temperature at the inlet to the boiler was the same in Case 1 and Case 2 and equal to 1000 K.

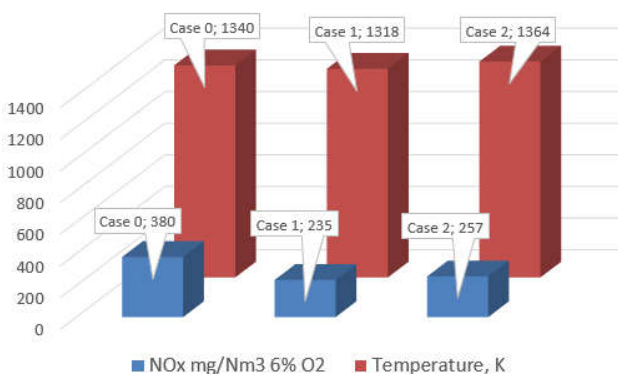
## 3 Results and discussion

The first stage of numerical simulations consisted of reproducing the coal combustion conditions (Case 0) using the inputs taken from the recommendations of the boiler and coal burner manufacturers. The average values: T=1340K, λ=1.23, O<sub>2</sub>=3,6% dry, and NO<sub>x</sub>=380mg/Nm<sup>3</sup> (6%O<sub>2</sub>, dry) at the furnace exit (Figs. 1 and 2) are within the range declared in the boiler manual and are taken as the reference points for the indirect co-firing analysis (Case 1 and Case 2).

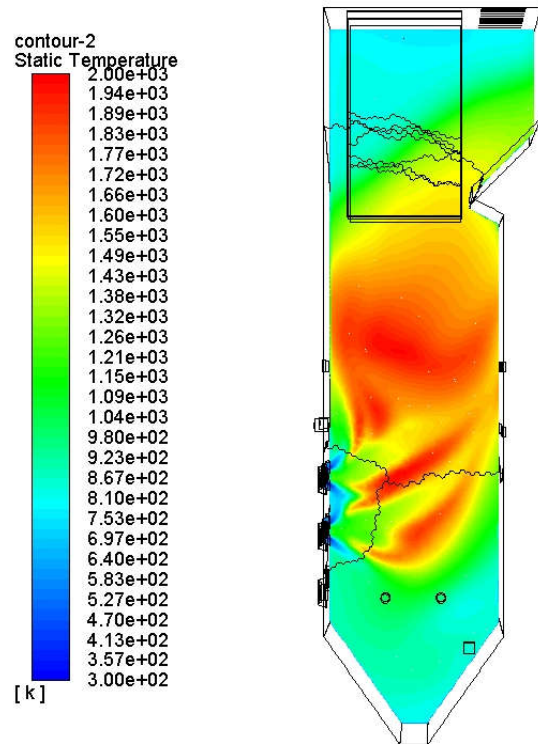


**Fig. 1.** Mean temperature distribution along the furnace elevations.

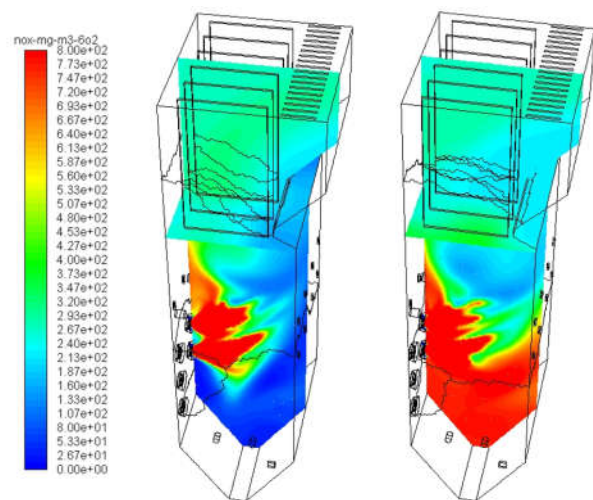
Fig.1 shows two peaks of temperature which are slightly displaced towards the rear wall because the burners are located on the front wall. The first peak above the burners is due to the course of the combustion process at region of burners. Next, the following drop in temperature reaches the OFA nozzles. The coal burnout results in slight increase in temperature above OFA nozzles corresponding to the second peak. The results of the second stage of simulations are related to Case 1 and Case 2. On one hand, the syngas low heat content relative to coal and increased moisture content resulting from methane and hydrogen combustion (Table 2) cause a lowering of flame temperature (i.e. flame cooling effect) in the burner zone as shown in Figs. 1 to 3. On the other hand, the syngas co-firing increases the temperature near the co-fuel nozzles.



**Fig. 2.** Mean temperature and NOx concentration at the furnace exit.



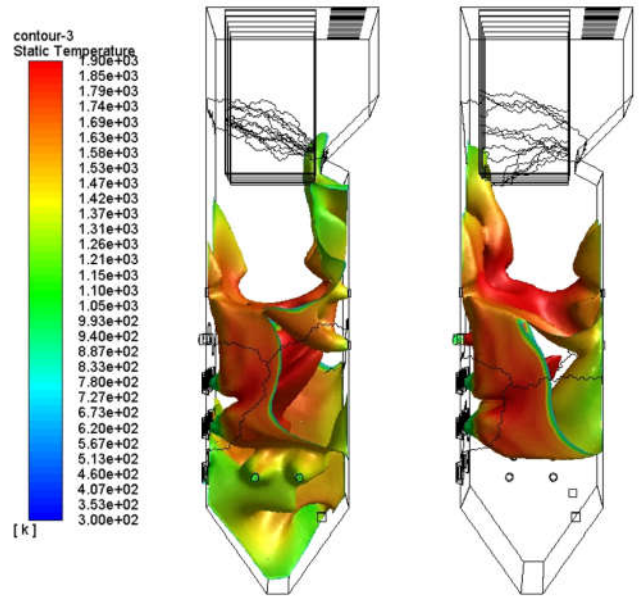
**Fig. 3.** Temperature profile in the furnace (Case 2)



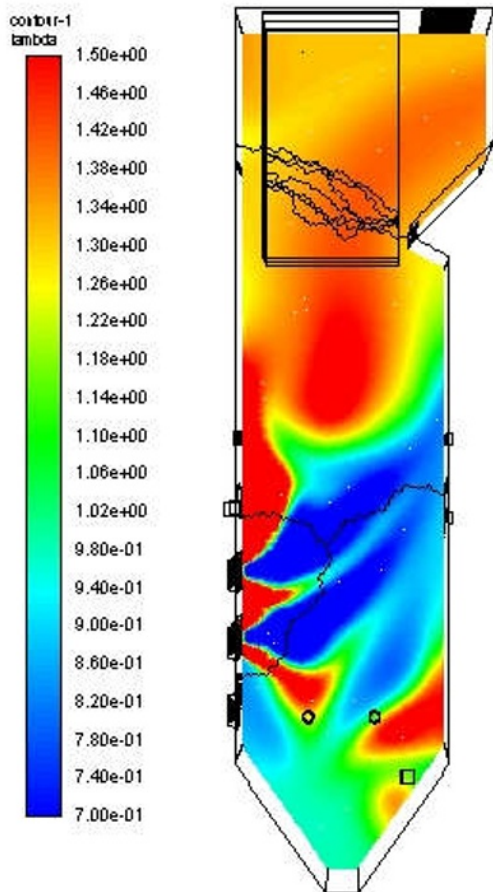
**Fig. 4.** NOx values [mg/Nm3] for the Case 1 and Case 2.

Comparing the mean temperatures at the furnace exit (Fig. 2), we can conclude that the amount of co-fuel injection in Case 2 is limited because such an injection at the elevation of the upper row of burners while increasing the amount of air in OFA nozzles raises the local temperature in the burnout zone as illustrated in Fig.3. Further increase of gas flow rate can cause an adverse impact on the boiler operation. The NOx concentration along the entire height of the furnace is higher for Case 2 than for Case 1 (Fig. 4) which results from higher combustion temperature (Fig.1). This does not apply to the local fuel rich zone in which the NO is

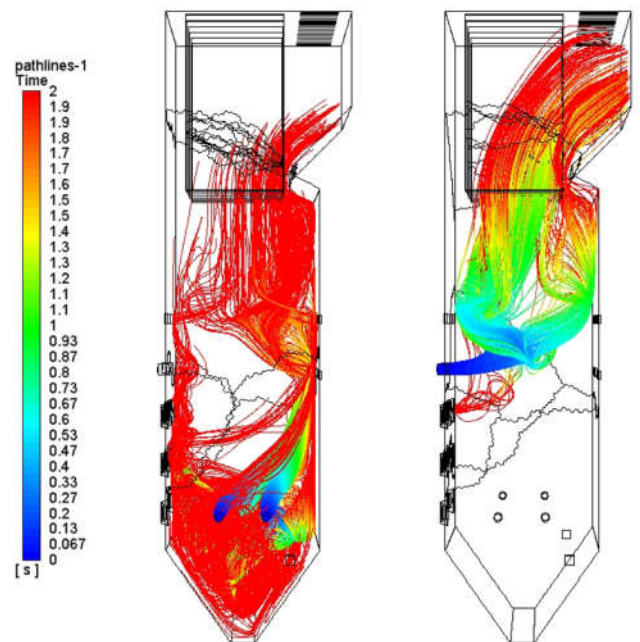
removed by hydrocarbons introduced into the furnace with the syngas injection in Case 2. The NO<sub>x</sub> concentration distribution obtained with Case 1 (Fig. 4) results from: (i) stable oxygen deficient conditions (Fig.5) in the zone of burners what is also illustrated in Fig.6; and (ii) limited successive uniform increase in oxygen concentration (Fig.5) up to levels of OFA nozzles and small amounts of NO production in the burnout zone; both due to the flame cooling effect. The syngas velocity ensuring its injection to the center of combustion chamber does not significantly affect the oxygen depletion near the screens. Decreasing the excess air in the main combustion zone has only a small impact on increasing the exposure of screens to low-oxygen and high-temperature corrosion in the region from burners to the level of OFA nozzles. Figs. 7 and 8 show that Case 1 and Case 2 ensure a long residence time of the co-fuels (more than two seconds) in the combustion chamber and not less than 2 seconds residence at the temperature above 1123K, respectively. The syngas can be therefore derived from gasification of agricultural residues biomass or containing such troublesome components as chlorine and alkali.



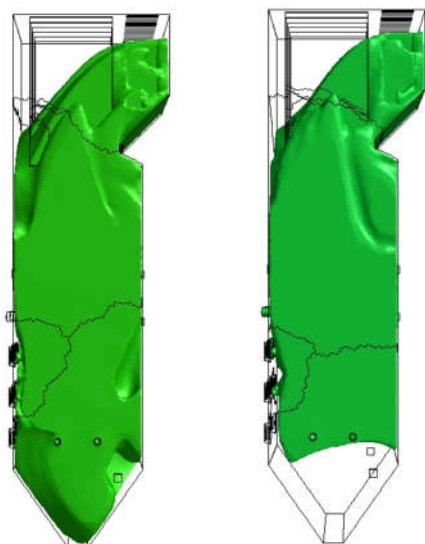
**Fig. 6.** Substoichiometric zone in the furnace (Case 1 - on the left, Case 2 – on the right) colored according to the temperature-color scale.



**Fig. 5.** Excess air ratio distribution in the furnace (Case 1).



**Fig. 7.** Pathlines released from the dedicated syngas nozzles (Case 1 - on the left, Case 2 – on the right).



**Fig. 8.** Temperature region above 1123K (Case 1 - on the left, Case 2 – on the right).

## 4 Conclusions

Our CFD simulations were directed at the evaluation of possibilities, limitations and benefits of the co-firing environmentally friendly biomass-derived syngas with coal in an older PC-fired boiler of type OP-230 with low-emission burners on the front wall still operating in Poland as heating units in combined heat and power (CHP) district energy plants. Particular attention was focused on the evaluation of reductions in NO<sub>x</sub> emissions relative to the coal combustion. For the biomass-derived syngas composition (Table 2) and 15% heat input replacement, two arrangements of nozzles dedicated to the syngas injection into the furnace were chosen to investigate the impact of their location on the reduction in NO<sub>x</sub> emissions. Ensuring the optimal operating conditions of the boiler, it was shown that the highest reduction achieved by means of such an improvement of the air staging via the dual-fuel technique can reach up to 38% (Case 1) and up to 32% (Case 2). The modelling results also showed that one can meet the requirements for co-firing of coal with syngas produced by gasification of agricultural and agro industrial residues [17,18] as well as solid recovered fuels (SRFs) containing such troublesome components as, for example, chlorine and alkali. Note that there is particular interest in gasification of agro biomass renewing every year. Fortunately, the mentioned troublesome component remain in the gasifier as slag and ash that are removed from there, therefore does not enter the boiler. Thus, it is easier to use ashes obtained from co-firing as additive for concrete production. The gasification of agro biomass and fuels formed from waste (SRFs, RDFs, REFs) is probably the forward looking technology that can even play a key role in the use of these combustible substances in the future energy sector. In the latter case, we would have to deal with a way to reduce the amount of waste deposited in landfills. The prospective environmental protection regulations relating to NO<sub>x</sub> emissions can be fulfilled by combining

the described technology with SNCR methods. It is also very important that the indirect co-firing enables reduction of carbon dioxide emissions proportionally to the syngas heat input.

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