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# Section 10. Physics

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## CFD simulation of production of NOx in coal-fired furnaces

***Abstract:*** Computational fluid dynamics (CFD) has been accepted as a powerful and effective tool for control and analysis of coal-fired utility boilers. Since coal burning in a utility boilers is a very complex process that comprises high-temperature reacting turbulent flow, particles transport and radiative heat transfer a reliable numerical simulation models of coal combustion requires high accuracy and careful interpretation of its numerical results.

**Keywords:** Computational fluid dynamics, Furnace, Combustion, Heat and mass transfer.

The object of this study was to improve an engineering tool by which combustion behavior of low-grade coalsin coal-fired utilities boilers can be predicted. Computational fluid dynamics code FLOREAN was used to predict performance of full scale pulverized-coal utility and introduce additional models to simulate boilers of various types and pollutant emissions formation in combustion process, to provide and validated the model parameters required for the simulations. The main motivation of the numerical combustion research is its use for design and development of the combustion chamber modifications and other important parameters needed for the effective boiler performance.

Computational Fluid Dynamics is a powerful tool increasingly used for the solution of flow and combustion related scientific and engineering problems. The applications of CFD tools have a broad variety: combustion, heat and power generation, turbo machinery, aerospace and auto industry, chemical engineering etc. In the field of combustion CFD is being widely used for the optimization of pulverized coal-fired industrial furnaces. The modern combustion systems of power generation must satisfy the number of demands. They are high degree of solid fuel burnt out with a minimum of excess air, lower slagging in the combustion furnace, operation with easily removed friable ash deposits, low NOx emissions due to combustion process modifications, acceptance of coal quality variations without significant reduction of combustion efficiency and boiler plant availability etc. Additionally there is requirements for the combustion systems to be in agreement with CO2 sequestration.

In the last years emissions regulations throughout the world are driving the need to modernize combustion equipment to reduce NOx and other pollutant emissions from power and steam generating plants. As environmental regulations on industrial emissions have increased, the focus of coal research has shifted more and more to understanding and reducing harmful pollutants such as nitrogen oxides.

Common methods of reducing NOx emissions during coal combustion include different primary and post-combustion measures. The objective of these methods is to assure that nitrogen is emitted as N2 rather than NOx. For example, staged combustion has achieved moderate success in reducing the amount on volatile nitrogen that is converted to NOx. However, because the nitrogen in the char is released by heterogeneous oxidation, staged combustion methods have little effect on NOx formed from nitrogen in the char. Low-NOx burners reduce NOx emissions by creating locally fuel-rich regions with sufficient residence time and appropriate temperatures in which volatile nitrogen is converted to N2 rather than NOx. Low-NOx burners have the potential to significantly reduce NOx emissions from coal combustion facilities and are currently the most economically favorable alternative.

This study also sought to enhance the industrial usefulness of the applied CFD tool. It is expected that with these additional features, the CFD complex FLOREAN will be very useful in improving combustion process of low-grade colas in different boilers of industrial enterprises. A three dimensional computational fluid dynamics code was used to analyze the performance of different boilers with pulverized coal combustion at different operation modes. The main objective of this study was to show a number of possibilities of the applied three-dimensional furnace modeling as an effective method for design, optimization and problem solving in power plant operation. Consequently, the FLOREAN — code was used to predict thermal and hydrodynamic aspects of airflue gases mixing in the near wall region and in inside of the combustion furnace. In the case of OFA technology study it was demonstrated that effective mixing between flue gases and over fire air is of essential importance for CO reburying and NOx reduction.

Air staging or two-stage combustion, is generally described as the introduction of over fire air into the boiler or furnace. Staging the air in the burner (internal air staging) is generally one of the design features of low NOx burners. Furnace over fire air (OFA) technology requires the introduction of combustion air to be separated into primary and secondary flow sections to achieve complete burnout and to encourage the formation of N2 rather than NOx. The Over fire Air (OFA) process involves diverting a portion of the combustion air from the primary zone and channeling it through a number of ports above the top row of burners. This creates two zones, an oxygen lean primary zone and a second oxidizing burnout zone where the combustion is completed. Primary air (70–90%) is mixed with the fuel producing a relatively low temperature; oxygen deficient, fuel-rich zone and therefore moderate amounts of fuel NOx are formed. The secondary (10–30%) of the combustion air is injected above the combustion zone through a special wind-box with air introducing ports and/or nozzles, mounted above the burners. Combustion is completed at this increased flame volume. Hence, the relatively low-temperature secondary-stage limits the production of thermal NOx. The location of the injection ports and mixing of overfire air are critical to maintain efficient combustion. Retrofitting overfire air on an existing boiler involves waterwall tube modifications to create the ports for the secondary air nozzles and the addition of ducts, dampers and the wind-box. For standard OFA systems the injection velocity through the ports is typically similar to that through the burners as the air is taken at the windbox or secondary air pressure. OFA has the advantage of needing no additional power consumption as the FD fan supplies the over fire air. Due to the higher air velocities, reduced residence times are required before the injection of the over fire air, to allow complete burnout of the coal particles.

A number of numerical experiments have been carried out with the aim to study influence of different technologies on formation of harmful emissions and furnace performance. First way is Over Fire Air technology. Over fire air (OFA) has been used for a long time on many coal fired boilers to achieve NOx reductions in addition to Low NOx Burners alone. OFA is a very cost effective way for reductions between 20 and 40% of the uncontrolled NOx emission.

The Over Fire air is injected by jet injectors at different planes at upper levels in the furnace chambers. The arrangement of the jets is similar to the burners arrangement. Mixture of the air and coal powder is injected in down furnace part.

The mixture then flows up and burns, while it transfers some of the combustion heat to the walls containing the water pipes. A fraction of 10% and 20% of the total combustion air is diverted from the burners and injected through the OFA in the upper part of furnace. Use of over-fire air can lead to reduction of NO emissions up to 28% in comparison with operation without OFA, while boiler thermal efficiency decrease to 0,17% due to increased losses by with unburned carbon and carbon monoxide corresponds up to efficiency loss. Velocity fields in vector shape for the level of OFA location for studied boiler is given on Figure 1.

Figure 2 shows temperature distribution via furnaces height for studied cases. Points are correspondent to experimental data (Fig.2) for furnace PK39 operation without OFA [2; 1]. Large differences in calculated and experimental values of temperature are observed in the region of ignition and extinguishing. Apparently, it could be due to the increased heat radiation which is set because of the supposition about complete combustion of carbon and in neglect by endothermic restitution of CO2 in coke resulting in increase of temperature.

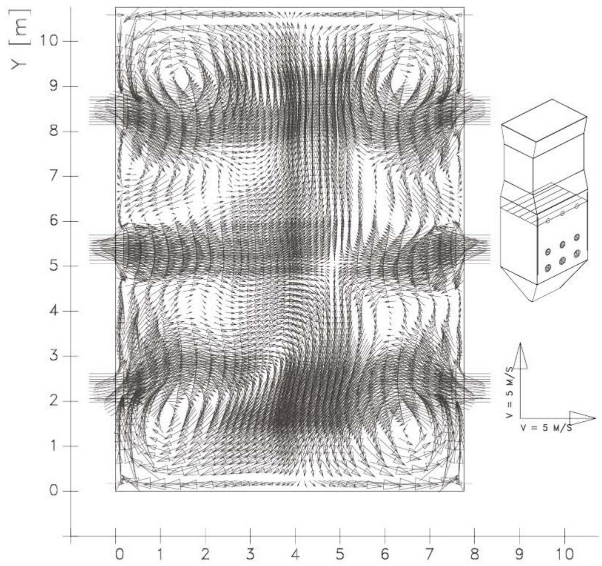
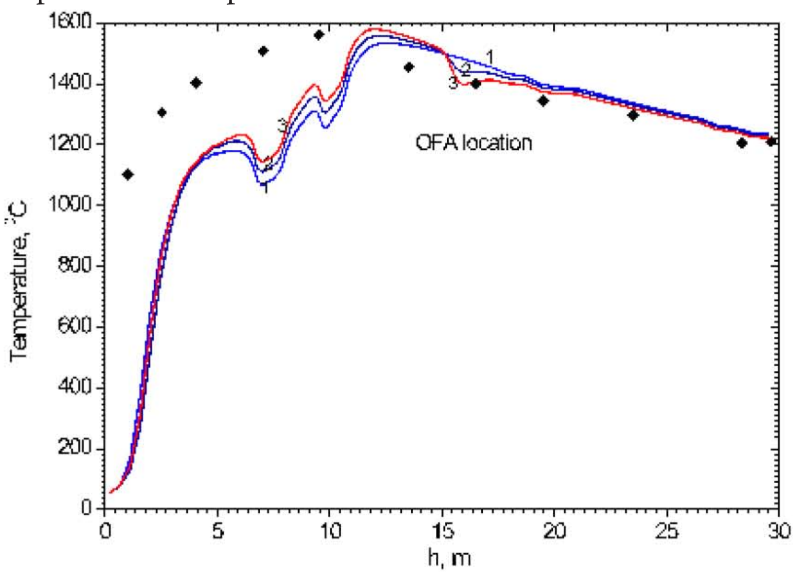



Figure 1. Velocity field

The influence of OFA on NOx formation in furnaces is shown on fig. 4. Use of over-fire air can lead to reduction of NO emissions up to 28% in comparison with operation without OFA, while boiler thermal efficiency decreases up to 0,17% due to increased losses by with unburned carbon and carbon monoxide (Fig. 7).




1 – base; 2 – OFA-10%; 3 – OFA-20%; (* – experiment)

Figure 2. Influence of OFA on temperature distribution in the furnace of PK39-steam generator

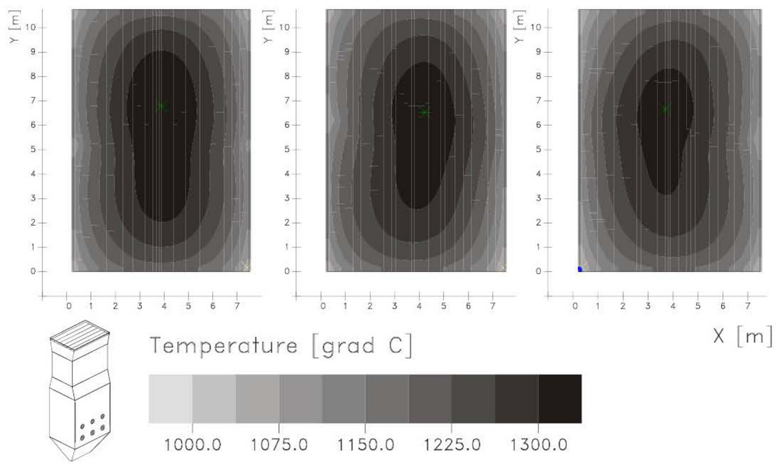



Figure 3. Influence of OFA on temperature at the furnace outlet of PK39-steam generator

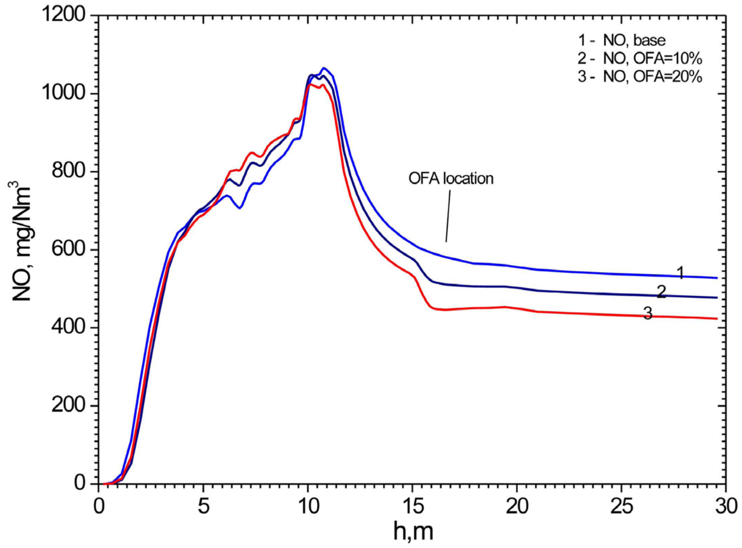



Figure 4. Influence of OFA on NO concentration in the furnace of PK39-steam generator

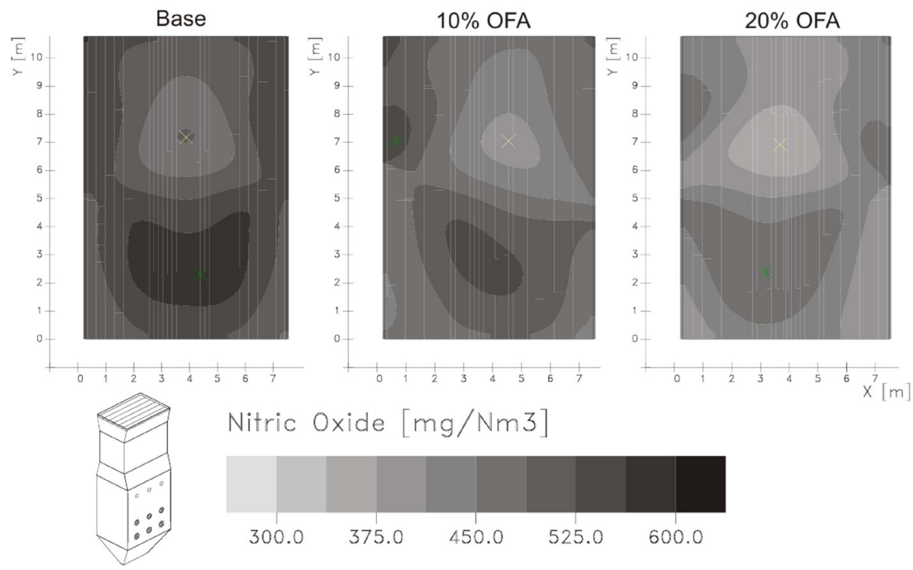



Figure 5. Influence of OFA on NO concentration at the furnace outlet of PK39-steam generator

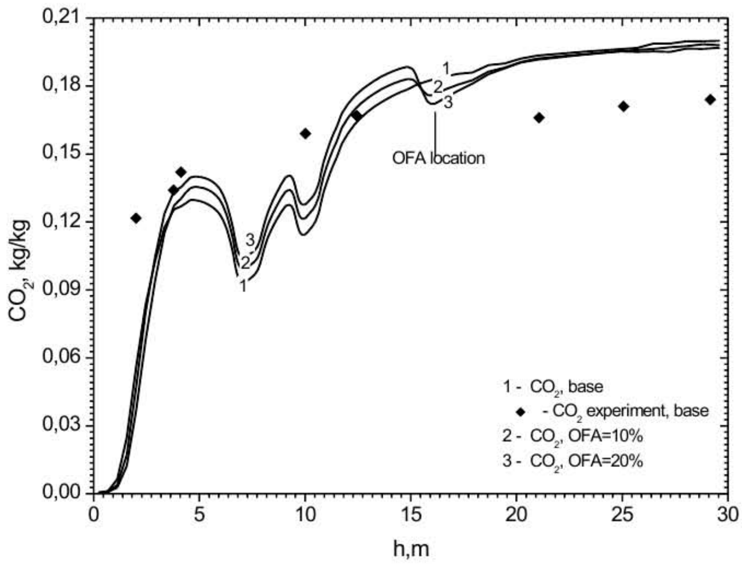



Figure 6. Influence of OFA on CO2 concentration at the furnace outlet of PK39-steam generator

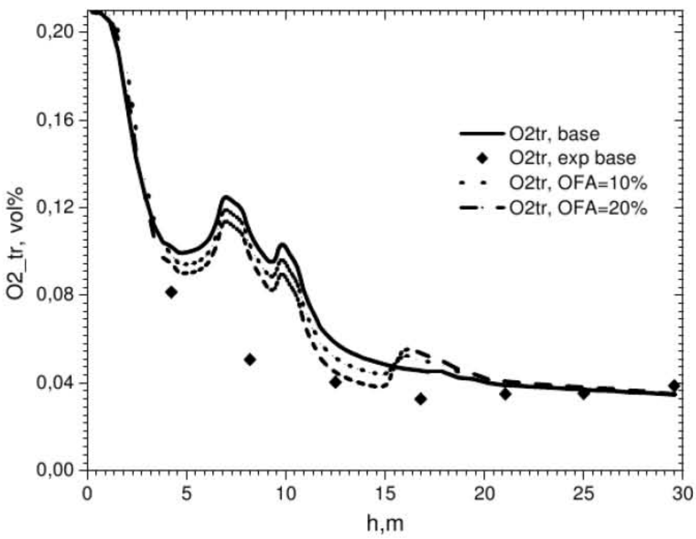



Figure 7. Influence of OFA on O2 concentration at the furnace outlet of PK39-steam generator

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## Autophase microwave-convertor with multiple energy input

**Abstract:** The article considers the two-section TWT with an autophase output section model. It presents the results of numerical modelling of the back conversation in autophase TWT at the multiple microwaves energy input. It has been revealed that the efficiency of the back conversation can be considerably increased by the choice of optimal low of the static potential profile change.

**Keywords:** numerical modeling, autophase section, microwave power, electron bunch, convertor.

The main mechanism of the autophase TWT work in the direct operation is described enough in the article [1]. The interaction mechanism in the autophase devices is the following: a bunch electron beam is gun in the interaction space, where the resistive coupling is much more, for example ten times more, than in a bunch section. Given certain conditions electron bunches are taken by the running wave in its potential minimum and drift with speed that equals phase speed of the wave, saving their stability. Shifting the bunch in the breaking

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