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Research paper

Assessing the impact of primary measures for NO_x reduction on the thermal power plant steam boiler

Goran Stupar [a,*], Dragan Tucaković [a], Titoslav Živanović [a], Srdjan Belošević [b]

[a] University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11120 Belgrade 35, Serbia
[b] University of Belgrade, "Vinča" Institute of Nuclear Sciences, Mihajla Petrovića Alasa 12-14, P.O. Box 522, 11001 Belgrade, Serbia

HIGHLIGHTS

- Modern steam boilers need to operate according to ecological standards.
- Possibility of applying some of the primary measures of NO_x reduction.
- Conventional calculations have no possibility to estimate sub-stoichiometric combustion.
- Develop a new method of connecting the calculations.
- Analysis shows the most favorable operation boiler regime (efficiency and ecology).

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ABSTRACT

The European normatives prescribe content of 200 mg/Nm^3 NO_x for pulverized coal combusting power plants. In order to reduce content of NO_x in Serbian thermal power plant (TPP) ☐Kostolac B' it's necessary to implement particular measures until 2016. The mathematical model of lignite combustion in the steam boiler furnace is defined and applied to analyze the possibility of implementing certain primary measures for reducing nitrogen oxides and their effects on the steam boiler operation. This model includes processes in the coal-fired furnace and defines radiating reactive two-phase turbulent flow. The model of turbulent flow also contains sub-model of fuel and thermal NO_x formation and destruction. This complex mathematical model is related to thermal and aerodynamic calculations of the steam boiler within a unified calculation system in order to analyze the steam boiler overall work. This system provides calculations with a number of influential parameters. The steam boiler calculations for unit 1 (350 MWe) of TPP ☐Kostolac B☐ are implemented for existing and modified combustion system in order to achieve effective, reliable and ecological facility work. The paper presents the influence analysis of large number of parameters on the steam boiler operation with an accepted concept of primary measures. Presented system of calculations is verified against measurements in TPP ☐Kostolac B☐.

1. Introduction

Converting energy into a form useful to people has its negative consequences – matters formed from the combustion process are harmful to humans and the environment. One group of harmful substances that are formed during this process refers to nitrogen oxides.

The level of NO_x emissions from thermal power plants in Serbia, exceeds the European standard of 200 mg/Nm^3 [1] in lignite combustion, which will be severe restriction from 2016 [2–4]. Various measures for reducing nitrogen oxides emissions have been developed in order to achieve the ecological standards in this domain. Nitrogen oxides are mainly formed by oxidation of nitrogen from the combustion air at high temperatures as thermal NO_x and by oxidation of nitrogen in the fuel as fuel NO_x which may occur at lower temperatures and which are dominant in coal-fired boilers. The formation of thermal NO_x is directly dependent on the local temperature in the flame, while the formation of fuel NO_x is primarily dependent on the nitrogen content in the fuel and oxygen available in the flame in the zone of particle combustion [5]. The first group of measures includes primary measures. The primary measures are based on nitrogen oxides emission reduction before

* Corresponding author.
E-mail address: gstupar@mas.bg.ac.rs (G. Stupar).

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and during their formation (before and during the combustion process). The primary measures are much cheaper, and although less effective, they are often applied during pulverized coal combustion. The most significant ones are: recirculation of combustion products, application of the burner with a low concentration of nitrogen oxides, multi-stage introduction of air and fuel and combination of these measures.

The existing measures of NO_x reduction can be further improved and their performance can be increased to the maximum level by using numerical simulations. Compared to experimental research numerical simulations are more cost-effective and could be carried out more easily, and thereby provide satisfactory results. In addition, numerical simulations play an important role in the design of new systems for NO_x emissions reduction, as well as the proper selection of measures for emissions reduction which shall be applied in the plants under development, as well as in the existing ones. This type of research has been successfully applied to describe the phenomena during the combustion of pulverized coal in the power steam boilers. Le Bris [6] and Diez [7] confirm the positive impact of over fire air (OFA) system on the reduction of nitrogen oxides in flue gases by comparing the results of numerical calculations and measurements on the thermal power plants. Korytnyi establishes dependencies between the characteristics of a large group of coals, the measured values of flue gas temperature and the concentration of NOx in the pilot unit using a computer fluid dynamics [8]. Choi in Ref. [9] points out the impact of fluid flows, temperature and oxygen concentration on the content NOx in the 500 MWe plant. Huang [10] deals with the optimization of air flow and consumption of pulverized coal after the implementation of primary measures, while Belosevic in Ref. [11] presented a detailed numerical analysis of the impact on the position of the flame in the power steam boiler. Nowadays, the numerical simulation is almost indispensable method for the process analysis and optimization. This aspect of the study leads Baek in Ref. [12] to the conclusion that the mixture of different coals has significant impact on carbon in ash while the changes in the content of NOx are negligible. The predictions in this field are also performed in Ref. [13]. The amount of unburned carbon and nitrogen oxide content in tangentially fired power plant are quantified. Zhou [14] and Belosevic [15] analyzed the aerodynamic effects on the flow field in the furnace as well as the efficiency of the combustion process. Adamczyk performed the CFD research in order to test the possibility of applying reburning process at large scale coal-fired boiler with a certain reference to the stability of the reconstructed plant operation [16]. Although there are a large number of papers which deal with the specific aspects of the calculation method, still there is a possibility for significant improvement in terms of the analysis of steam boilers in general. Therefore, Chui in cooperation with CanmetENERGY (Canada) began his work in order to produce a user-friendly tool for modeling processes in the coal-fired boilers aiming to increase the efficiency and to reduce pollution in the 11 selected energy units [17]. Concerning this, in the early stages of designing one acquires a clear insight of the NOx concentration, as well as on the efficiency and stability of the processes themselves. Therefore it is possible to predict if the plant with its main purpose meets increasingly demanding environmental regulations.

In order to research the possibility of applying some of the primary measures of nitrogen oxides reduction as well as analysis of their effects on the operation of steam boilers in general, the modeling of lignite combustion process in the steam boiler furnace unit 1(350 MWe) in the TPP □Kostolac B□ has been carried out. Mathematical model of radiating reactive turbulent two-phase multi-component flow is extended by the mathematical submodel of formation and destruction of fuel and thermal nitrogen oxides for the purpose of a comprehensive description of the process in the power steam boiler furnace for combustion of coal dust. Such a complex mathematical model is associated with integral thermal and aerodynamic calculations of the boiler by the use of an in-house developed software code [18] (based on Normative method) within a unified calculation system for the analysis of the steam boiler operation as a whole. Park [19] stressed the importance of such connections of numerical calculation of the process in the gas stream of the steam boiler with one-dimensional calculations of water and steam in plants, and this approach provided good matching with the measured values. In this way, a defined system allows calculations with the change of effective parameters in the widest range. On the basis of this system, calculations of the steam boiler unit 1 TPP □Kostolac B□ for the existing and reorganized (modified) combustion system were aimed at evaluation of the quality of its operation. This paper presents an analysis of the impact of a number of parameters on the steam boiler operation with the adopted concept of primary measures.

In order to show the impacts of some parameters on the operation of the considered steam boiler after the introduction of the primary measures, some relevant results of the calculation system are presented in the case of excess air coefficient change, total intake of air and recirculation of cold flue gases. All calculations have been made for nominal load and the fuel that is currently used at the power plant.

2. Technical description of the steam boiler

A simplified layout of a steam boiler unit 1 TPP □Kostolac B□ is shown in Fig. 1.

2.1. Operational characteristics of the boiler

• Main steam mass flow rate	$D = 277.8$ kg/s
• Main steam pressure	$p_s = 18.6$ MPa
• Main steam temperature	$t_s = 540.0$ °C
• Reheated steam mass flow rate	$D_r = 248.8$ kg/s
• Reheated steam pressure	$p_{rs} = 4.375$ MPa
• Reheated steam temperature	$t_{rs} = 540.0$ °C
• Steam pressure at the reheated inlet	$p_r = 4.604$ MPa
• Steam temperature at the reheated inlet	$t_r = 334.0$ °C
• Feed water pressure	$p_{fw} = 20.46$ MPa
• Feed water temperature	$t_{fw} = 255.0$ °C

Steam boiler consists of an economizer (1), evaporator placed in the furnace (4), three superheaters and a two reheaters. Temperature control of fresh and reheated steam is done by the injection of water into desuperheaters placed between the corresponding heating surfaces.

The boiler is equipped with eight plants for pulverized coal preparation. Coal grinding and drying is carried out in fan mills with inertial separators at the outlet. Drying is done by flue gases which are brought through recirculation ducts (13) from the furnace outlet into the mill. Temperature control of mill gaseous mixture is done by the primary air which is brought through the connection (15) into the head of recirculation duct (14) and by cold recirculation of flue gases from the boiler outlet brought through the connection (16). The classifier of the mill gaseous mixture is located behind the mill separator which divides it into the two flow streams: primary and secondary. There is a channel for mill gaseous mixture (18) behind the classifier whose cross-section gradually decreases in the direction of flow. Behind it, the primary current is taken into the bottom (19) and upper (20) level of the main burner