Nedim Ganibegović, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 10, Issue 7, (Series-II) July 2020, pp. 01-09

RESEARCH ARTICLE OPEN ACCESS

Numerical Prediction of Risk Areas for Low Oxygen Corrosion Damages in Furnace of the Retrofitted Tangentially Fired Boiler

Nedim Ganibegović*, Indira Buljubašić*, Amel Mešić*, Izudin Delić*
**Faculty of Mechanical Engineering, University of Tuzla, Bosnia and Herzegovina*

ABSTRACT
The modern project solution, which has been implemented on the coal combustion system in Thermal Power Plant Tuzla Unit 6, has enabled the application of low emission concept of combustion and reduction of ash slugging on walls of combustion furnace, but analysis of the operation of boiler has shown significant deviations of the characteristic operating parameters obtained by the exploitation measurements compared to their design values. Previous CFD analysis that has been conducted on the aero-mixture channel and low emission burner has shown that current system of aero-mixture separation has a complex impact on combustion process inside the furnace. In order to determine the scope of the proper coal distribution in the specific boiler furnace on the combustion process, results of previous CFD analysis in combination with data obtained with classical mathematical models, have been used as inlet data for CFD simulation of combustion process. Obtained results in this paper should enable better understanding of combustion process, determination of critical process parameters that have main impact on efficiency of the boiler and its service life. From CFD results it's clear that shape and position of flame depends on operating mills configuration and coal rate distribution per coal burner height.
Keywords - pulverised-coal boiler, coal combustion process, NO_X emissions, fireside corrosion.

Date of Submission: 18-06-2020 Date of Acceptance: 06-07-2020

I. INTRODUCTION

In the coal-fired power plants, a big challenge is improvement of combustion process enforced by environmental concerns. Regulations and common public pressure for reducing NO_X and SO_X emissions become stricter and meeting them must be achieved by both new and old production units. The big challenge for the electricity producers from coal-fired power plant will be to ensure flexible operation due to increasing share of renewable sources of energy in the market. That means that coal units have to adapt to market needs and work with increased load variations during the day. Working with changing load requires constant monitoring and control of the operating parameters of the boiler in required intervals in order to maintain high efficiency and required levels of gas emissions. It is currently possible to achieve the required quality of exhaust gasses with primary and secondary measures. Use of a low-emission burner as a standard primary NO_X reduction measure can also be applied to existing boilers. This was done by retrofitting during boiler revitalization.

There are a number of operational problems of coal-fired boilers, which are suspected to be caused by non-uniform combustion in the furnace [1]. One source of non-uniform combustion is uneven distribution of fuel inputs to the furnaces. The optimization process for emission reduction can be done by optimizing the amount and distribution of fuel and air supplied to the boiler [2]. Homogenous temperature distribution of flue-gas in the boiler furnace promotes lower emissions of NO_X, CO, and minimizes total organic carbon (TOC) content in ash. A temperature measurement can also be applied to verify the results of computational fluid dynamics (CFD) modeling [3]. Results of CFD modeling [4] can be used at the stage of the combustion process optimization to provide complete information about the process. A comprehensive large-scale furnace CFD model should be capable of properly predicting trends in NO_X reduction by means of primary [5] and secondary [6] methods. CFD modeling has been extensively applied to provide information on the complex phenomena in tangentially fired boiler [7–9]. In [7], comparison between the boilers combustion characteristics was carried out based on the CFD simulation. In [8], different operation regimes of pulverized coal furnace have been investigated with the CFD code. The simulation results show a good agreement with the measurement. Similar purpose was achieved in [9]. Additionally, a grid refinement study was performed. The flow field and temperature distribution inside the tangentially fired boiler were analyzed under the operation conditions [10]. In [11], a three-dimensional numerical simulation was carried out to study the pulverized-coal combustion process in a tangentially fired ultra-supercritical boiler. The strategic role of energy and the current concern with greenhouse effects enhance the importance of the studies of complex physical and chemical processes occurring inside boilers of thermal power plants. Numerical simulations of a pulverized coal combustion field are effective for understanding coal particle behavior in the furnace [12-16].

The state of the art in computational fluid dynamics and the availability of commercial codes encourage numeric studies of the combustion processes. In the present work, a commercial CFD code, ANSYS, was used to study the pulverized-coal combustion process in a 223 MWe thermal power unit, with the objective of simulating the operation conditions and identifying factors for corrosion damage.

II. DESCRIPTION OF THE CASE STUDY

Unit 6 boiler in Thermal Power Plant Tuzla, B&H, operates in the block system with generator of 223 MW power. The boiler is of the "П" shape and has a tangential arrangement of jet burners. Brown coal is pulverised and blown with combustion air into furnace, with a dry process of slag removal from the furnace. Under the maximum continuous rating of operating conditions, the unit produces 167 kg / s of steam flow through the main steam piping at 13.5 MPa and 540 °C [17]. In the year of 2012, the combustion system with low NO_X pulverised coal jet burners was modernized and two levels of OFA air supply were introduced for primary NO_X reduction. Specificity of the analyzed furnace is the geometric arrangement of the jet burners on the furnace walls, where there are two burners on the front and back and one burner on the sides of the furnace. The jet burners are inclined at an angle of -10 ° with respect to the horizontal plane, i.e. towards the furnace funnel. This concept of low-emission burners should allow sufficient time for complete fuel conversion.

2.1 IDENTIFICATION OF PROBLEMS IN BOILER OPERATION

After modernization of the combustion system of the boiler, it was concluded that the solution does not allow the boiler to operate in a wider range of process parameters. A nominal temperature of secondary steam at the boiler outlet can only be achieved for boiler loads higher than 90%, while at lower boiler loads (<75%), the temperature is lower than 520 °C [18]. Also, after the modernization, the low-oxygen corrosion is appeared on the furnace wall tubes, as shown in Fig. 1.

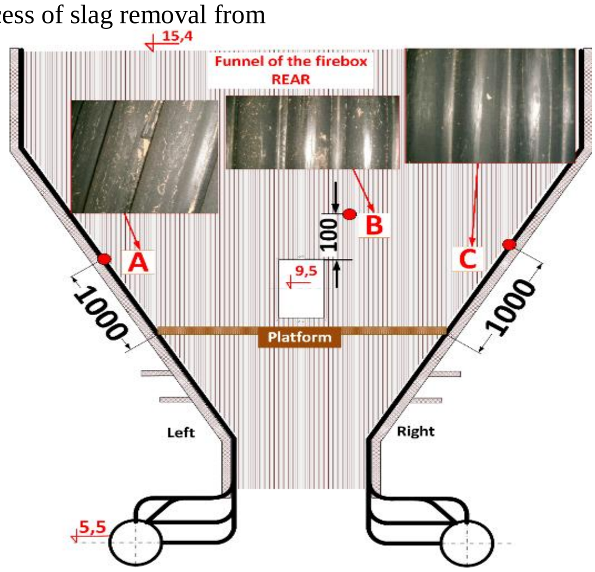

Figure 1 Sketch over location of known corrosion damages

Table I: The design and measured thickness at 9 tube rows in the four positions indicated at Fig. 1.

Date of measures	Measured thickness [mm] and ordinal number of the evaporator pipes								
	7	8	10	27	29	30	33	34	37
30.12.2015.	5,3	5,3	5,9	5,9	5,9	5,9	5,9	5,9	6,0
19.11.2016.	5,3	5,8	5,2	5,6	5,5	5,6	5,7	5,8	6,0
09.05.2017.	4,9	4,9	5,0	4,8	4,8	4,8	4,9	4,8	4,9
29.04.2019.	4,9	4,9	5,0	4,7	4,8	4,7	4,8	4,8	4,7

The wall thickness was measured on the selected evaporator tubes from the formed platform in the checkup door area at the back of the furnace funnel, Table 1. The measurement results indicate a trend of the pipe wall decrease at the characteristic positions in the furnace funnel zone. Although low NO_X combustion techniques can effectively reduce NO_X formation for the reductive atmosphere of the main combustion zone, high CO concentration also accelerates high-temperature corrosion of water-cooled walls and increases the burn-time of pulverized coal. A corrosion risk of evaporators is caused largely by reducing atmosphere near the walls of the furnace and by occurrence of zones with deficit of oxidant and high concentrations of CO.

The studies as [19] have shown that O_2 and/or CO measurement in the boundary layer of evaporators can be a good indicator for corrosion risk assessment for a given boiler and fuel. Given the sub-stoichiometric combustion conditions in the primary area of the furnace, it is necessary to allow the complete gasification and combustion of solid fuel components as soon as possible. On the other hand, the creation of zones in the furnace where there may be “too much” air involved in the combustion process in the immediate vicinity of the burner has the effect of increasing NO_X emissions. Uneven distribution of air and fuel by individual pulverized coal burners can cause reduction zones to appear in the boundary layer of the furnace. The overall temperature level in the boiler furnace is of great importance for the pulverized coal combustion process. Insight into the shape of the flame and the temperature value at the cross-section of the furnace creates the possibility of controlling the spatial distribution of temperatures in the furnace. In this sense, it is necessary to achieve the optimal distribution of pulverized coal by the height of each individual burner in order to obtain a uniform temperature distribution in the boiler furnace. Adjusting the optimum amount of pulverized coal per burner in practical conditions is based on changing the position of the dividing dumper located in the air mixture duct behind each individual mill. This results is a change in the shape and position of the flame, i.e. the temperature distribution in the furnace. For a clearer view of quantitative influence of the distribution of pulverized coal on the combustion process, amount of pulverized coal was varied in the range of 70-50% i.e. 50-30% to the upper and lower part of burners, respectively.

III. MODELING METHODOLOGY

3.1 PHYSICAL MODEL

The performed simulations are based on a 223 MWe wall-fired boiler, with the configuration and size parameters illustrated in Fig. 2. In this model, the geometric dimensions of the simulated boiler were 45 m (height), 13 m (width), and 13 m (depth).

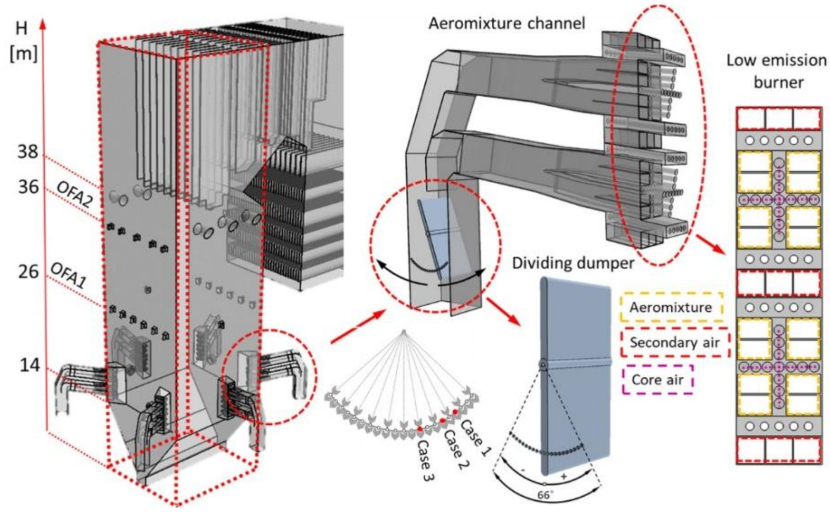

Figure 2 Geometry of the simulated second boiler at the Tuzla power plant

3.2 NUMERICAL ANALYSIS

A comprehensive historical review of the modeling approaches and techniques of pulverized coal boilers is given in [20], pointing out very different standpoints and objectives. Numerical simulation of pulverized coal combustion on tangential boiler type OB650 were carried out by a computational fluid dynamics code. Comprehensive numerical code consists of multiphase flow model and combustion model with appropriate sub models for devolatilization and char burnout, convection and radiation heat transfer between particles and gases, and thermal and fuel NO formation/destruction. The mesh was constructed for the boiler using 872.538

cells.

Setting up a numerical model for the purpose of simulating pulverized coal combustion presupposes preliminary mathematical modeling of the continuous gas phase flow and its interaction with the discrete phase with coal particles, and afterwards, modeling of the chemical reactions of the participating components and the heat transfer. Since such flow is a turbulent flow of the multi-component gas phase, it is described by a very complex system of partial differential equations for maintaining mass (continuity), equations for changing the amount of fluid motion and a differential equation for particle motion. The thermodynamic and transport properties are derived according to the equations of state and empirical relations. The system of equations is closed by a realistic, i.e. realizible k-ε model of turbulence [21]. The effect of gas turbulence on particles is covered by a stochastic tracking model that provides the required computational efficiency. The partial differential equation of conservation in the Euler field, with additional original terms due to the presence of solid particles S_P^{Φ}, according to the PSI Cell method, has the following form:

$$\frac{\partial}{\partial x_j}\left(\rho U_j \Phi\right) = \frac{\partial}{\partial x_j}\left(\Gamma_{\Phi} \frac{\partial \Phi}{\partial x_j}\right) + S_{\Phi} + S_P^{\Phi} \qquad (1)$$

Where Φ is an independent variable and U_j is the velocity component in the direction x_j, ρ is the fluid density; Γ_{Φ} is the diffusion coefficient; S_{Φ} is the original member. Thus, the transport equation is valid as the mass conservation equation when Φ = 1, the moment conservation equation if the independent variable Φ represents the velocity component; energy equation if Φ is enthalpy; or transport equation when Φ is a scalar variable such as the mixture fraction function [22]. In the mathematical model applied in this paper, heterogeneous chemical reactions were considered, whereby the process of combustion of coal particles consists of three phases: drying, devolatilization and combustion of char. The dual kinetic model was chosen as the model of coal devolatilization [23]. A non-premixed model was selected for the combustion model, which treats the individual processes of turbulence and chemical reaction together, assuming that in the equilibrium chemistry model a reaction is fast, so that chemical equilibrium is always present at the molecular level. This "equilibrium model" is suitable because it does not require knowledge of detailed chemical kinetic data. The chemical reaction of the mixture consists of a total of 20 volumetric components. The interaction between turbulence and chemical reaction is calculated using the probability density function PDF model. Heat transfer by radiation in gray absorbent and emitting medium was taken into account by using a discrete ordinates model (DO radiation model), with the weighted sum of the gray gases model for gas absorption. Particulate emission, reflectivity and scattering coefficient are also included in this model in the calculation of radiation heat transfer. The discretization of nonlinear partial differential gas phase equations for the 3D problem was performed using the control volume method, using a hybrid differential scheme. The coupling of the continuity equation and the equation of the law of quantity of motion is performed by the SIMPLE algorithm, and the stabilization of the iterative calculation procedure is provided by the sub-relaxation method. The numerical iterative procedure defining the model for the formation and destruction of nitrogen oxides is approached after the obtained convergence of the temperature field, i.e. after obtaining the numerical results of the combustion and heat transfer process, assuming that the NO_X concentration is small enough to have no effect on the combustion process of the coal in the furnace. Total NO_X is formed as previously stated, mainly as thermal NO_X from the fuel, while the share of prompt NO_X in this context is minor and is therefore neglected in this paper. Numerical model allows change in the selected process parameters and as a result gives the current and concentration field of the multicomponent gas mixture, the distribution of the temperature field and the data defining the movement and combustion of pulverized coal particles.

3.3 SIMULATION CONDITIONS

The properties of the lean coal fired in this boiler are presented in Table 2, and the coal particle is assumed to obey the Rosin-Rammler algorithm.

Table II: Dry ash free analysis of the coal and coal particle diameter distribution.

	Parameter	**Value**
Elementary analysis DAF [%]	C	69,23
	H	5,16
	O	21,37
	N	1,21
	S	3,03

Low heating value Q_{net} [kJ/kg]	In received state	16.050
Particle diameter distribution [µm]	Min/max diameters	90/500
	Mean diameter	155,6
	R-R spread parameter	1,62

The results of one numerical model (multiphysics flow) were used as boundary conditions of the other numerical model, which resulted in the so-called coupling of two CFD models. Coal kinetic parameters were adopted in accordance with the available experimental data for the kinetics of fuel from operation [26]. There, secondary air is defined as the gas injected only in primary zone after pulverized coal ignition, which excludes the OFA. Hence, the feeding gas can be divided into primary air, secondary air and OFA. The stoichiometric ratio (SR) is defined as the ratio of the amount of O_2 actually supplied to that for stoichiometric combustion.

Table III: Main parameters of pulverized coal for base case of dividing dumper in aero-mixture channel

Parameters	Unit	Burners					
		B1	**B2**	**B3**	**B4**	**B5**	**B6**
Temperature	[°C]	-	175,7	179,1	182,6	179,3	162,0
Velocity of aero-mixture in channel							
Upper burner	[m/s]	-	29,48	31,0	29,48	32,63	31,0
Lower burner	[m/s]	-	20,54	19,0	20,54	17,35	19,0

In order to select the most favorable position of the control valve for the distribution of coal dust by the height of all 6 pulverized coal burners, an analysis was made for scenarios that defined the distribution of coal by the height of the burner (upper/lower) in approximately the following ratios: 70:30 (case 1), 60:40 (case 2) and 50:50% (case 3), respectively.

Table IV: Summary of the simulation cases for various distributions of coal dust by burners height

Parameter	**Unit**	**Case 1**	**Case 2**	**Case 3**
Distribution of coal on upper/lower part of burners	%	70/30	60/40	50/50
Total mass of coal flow L/U	kg/s	24,06/10,31	20,68/13,75	17,19/17,19
Total mass of secondary air flow	kg/s	94,58		
Total mass of total OFA air flow	kg/s	30,85		

IV. RESULTS AND DISCUSSION

The purpose of this work is to study influences of applications of different coal distribution per height of coal burner, on the performance of tangential boiler presented in this paper. The analysis of the vertical distribution of the flame in the boiler furnace was performed in order to determine the most favorable position of the dividing dumper in terms of boiler performance and output process parameters that determine the quality of the combustion process. CFD analysis was performed for scenarios that defined the distribution of coal powder by the height of each working burner (upper/lower) in the following ratios: 70:30, 60:40 and 50:50% respectively.

4.1 TEMPERATURE DISTRIBUTION

From CFD results it's clear that shape and position of flame depends on operating mills configuration and coal rate distribution per coal burner height. Parts of furnace in which the corresponding combustion takes place are accompanied by an increase in the temperature of the combustion products, which can be seen by the T and O_2 diagrams in the vertical cross section of the furnace, Fig. 3. These are, at the same time, the parts with the lowest mass fractions of O_2.

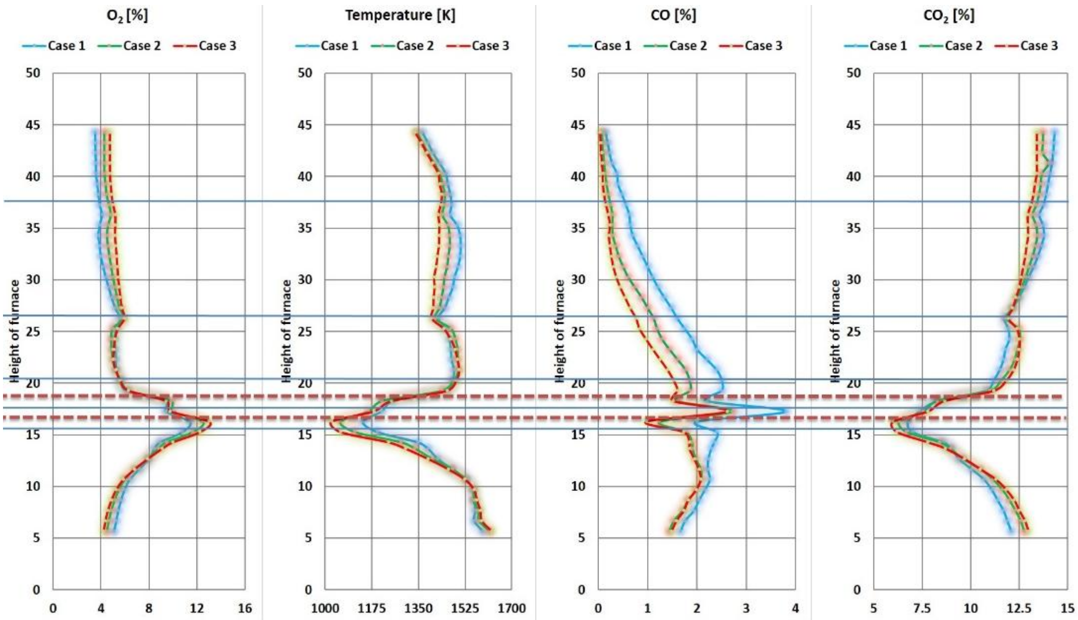

Figure 3 Diagram of temperature T and mass averaged of O_2, CO, CO_2

Regarding the cases investigated in this study it can be seen that flame temperature distributions of all cases showed tendency toward the out off service burner (in analised case it is mill No1). The shape and position of the flame in the characteristic cross sections of the furnace is shown in Fig. 4. It can be observed that the temperature field has the highest intensity in the central area of the furnace, where the most intense combustion takes place.

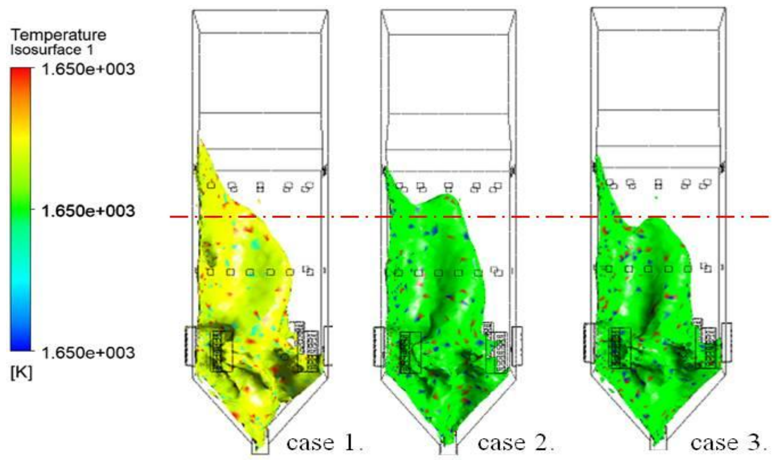

Figure 4 Iso-surfaces of the combustion flames at 1650K (view of front side of the furnace)

The mean temperature of the combustion products in the burner zone where secondary air is introduced is 1054K, raises to a maximum value of 2001K in the central part of the furnace, for case 2, while the lowest temperature is registered for case 3, and is 1941 K. The results indicate that there is a direct functional dependence of the position of the dividing dumper for the vertical distribution of the amount of coal powder on the burners and the temperature distribution in the boiler furnace. Combustion products have a significant temperature deviation in the central burner zone due to the asymmetric distribution of coal powder burners currently in operation.

4.2 DISTRIBUTION O_2

The composition of the gas environment in the furnace is defined by excess air and significantly affects the temperature profile in the furnace and the gas tract of the boiler, which, in addition to the production of pollutants, also affects the energy efficiency and availability of the boiler plant. The oxygen with the secondary air required for combustion is introduced into the furnace via the air nozzles on the coal powder burners. The concentration of O_2 in the furnace is therefore highest near the burner. In this area, a process of intense oxygen consumption takes place. A change in the concentration of coal powder by the height of the burner leads to a change in the relative air content of the air mixture resulting in a change in the local concentration of O_2 in the furnace, as shown in Fig. 5.

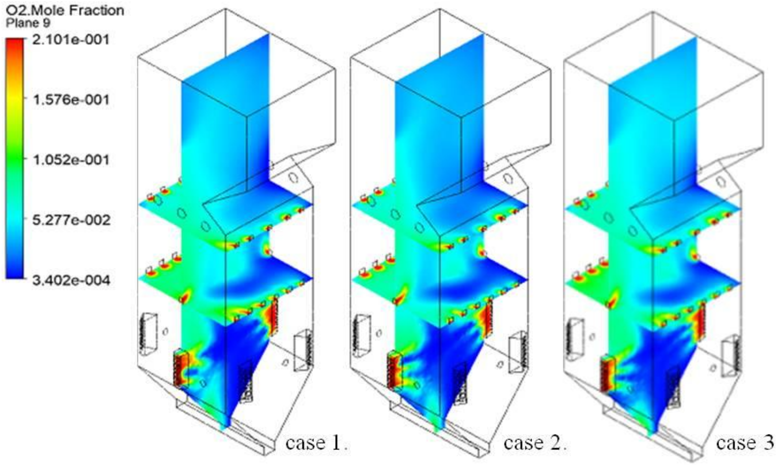

Figure 5 Mole fraction of vertical and horizontal distribution O_2

4.3 LOW-OXYGEN CORROSION

CO emission is an important parameter to measure the quality of coal combustion. The results of the numerical simulations made it possible to simultaneously predict the concentration of O_2 and CO near the evaporator pipes of the furnace for different boundary conditions of the numerical model. The value of the concentration of O_2 and/or CO in the boundary layer of the evaporator tubes in the boiler furnace may be a good indicator for assessing the risk of low-oxygen corrosion [19].

Improving the combustion conditions can bring many benefits to the combustion characteristics and reducing the high temperature corrosion problems on the surfaces of the evaporator tubes. The ability of the burner to perform a good mixing of air and fuel depends on the flow of the air mixture and the secondary air, which may vary, depending on the design of the burner and the operating conditions. In order to improve the quality of combustion process control, an analysis was carried out regarding the evaluation of the possibility of improving the regulation of the amount of air on the boiler. In this regard, a case with equal air/fuel (A/R) ratio was analyzed for each coal dust burner in operation, to minimize the occurrence of local excess air in the primary combustion zone.

The distribution of CO by the selected vertical cross section of the furnace is given in Fig. 6. On the left side of the combustion wall, a larger boundary layer of the reducing atmosphere can be observed in the case of a boiler operation in which the secondary combustion air balancing is not performed in such a way that the air/fuel ratio is equalized, but in the case when the air/fuel ratio is equalized between the burners. In both analyzed cases, the dividing dumper for the distribution of coal dust per burner was in the same working position (position with distribution 70:30 - upper/lower part of the burner) and with the same configuration of the mills in operation (in the analyzed case mill No.1 is in the reserve).

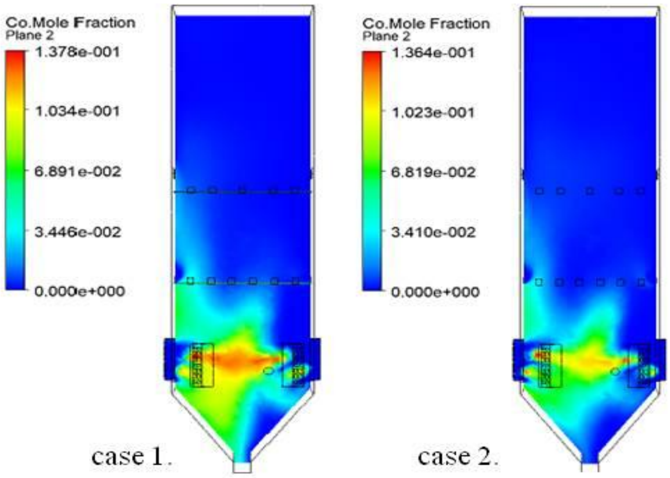

Figure 6 CO mole fraction (left -A/F unbalanced, right -A/F partially balanced)

Such conditions of deep reduction atmosphere in the lower zone of the furnace allow the ash particles from the gas stream to penetrate the boundary layer and settle on the wall tubes. Thus, there is a serious risk of the appearance of high-temperature corrosion of the wall tube system under the formed deposits, since CFD calculations have registered maximum CO concentrations of 8% in case 1 and about 5% in case 2.

V. CONCLUSION

The probability of high temperature corrosion of wall furnace is increasing with the application of primary NO_X reduction measures, in particular with implementation of air staging method. High-temperature corrosion is often consequence of poor combustion resulting in flame position near the walls and creating a reduction atmosphere in the furnace. The regulation of shape and position of the flame, both height and side, is of practical importance for heat transfer and thermal load on the wall pipes in the furnace. Too high a flame position can cause thermal overload of the superheaters, or if the flame in furnaces goes down too low it is more likely that there will be increased wall slagging and high-temperature corrosion in the furnace funnel.

With appropriate distribution of the air-coal dust mixture per burner height and with moderate A/F ratio on the burners, more uniformly shape of the flame in furnace is achieved influencing to the overall boiler performance and effectively suppressed NO_X formation on exit of furnace.

It is clear from the results of the CFD analysis that there is a good chance that the occurrence of reduction zones in the lower part of furnace can be limited and negative effect resulting from high-temperature corrosion can be reduced.

REFERENCES

[1]. A.A. Vetter, R.S. Vetter, Balancing pulverized coal flows in parallel piping, *Journal of Engineering for Gas Turbines and Power, 107(7)*, 1985, pp. 679-684.

[2]. D. Nabagło, P. Madejski, Combustion process analysis in boiler OP-650k based on acoustic gas temperature measuring system, *Proceedings of 3rd International Conference on Contemporary Problems of Thermal Engineering CPOTE 2012*; 2012, pp. 18–20.

[3]. N. Modliński, P. Madejski, T. Janda, K. Szczepanek, W. Kordylewski, A validation of computational fluid dynamics temperature distribution prediction in a pulverized coal boiler with acoustic temperature measurement, *Energy, 92*, 2015, pp.77– 86.

[4]. E. Chui, H. Gao, Estimation of NO_X emissions from coal-fired utility boilers, *Fuel. 89*, 2010, pp. 2977–2984.

[5]. S. Dal Secco, O. Juan, M. Louis-Louisy, Y.V. Lucas, P. Plion, L. Porcheron, Using a genetic algorithm and CFD to identify low NO_X configurations in an industrial boiler, *Fuel, 158*, 2015, pp. 672-683.

[6]. N. Modliński, Numerical simulation of SNCR (selective non-catalytic reduction) process in coal fired grate boiler. *Energy, 92*, 2015, pp. 67-76.

[7]. N. Modliński, Computational modeling of a utility boiler tangentially-fired furnace retrofitted with swirl burners, *Fuel Processing Technology, 91*, 2010, pp. 1601-1608.

[8]. S. Belosevic M. Sijercic, S. Oka, D. Tucakovic, Three-dimensional modeling of utility boiler pulverized coal tangentially fired furnace, *International Journal of Heat and Mass Transfer, 49*, 2006, pp. 3371-3380.

[9]. S. Belosevic, M. Sijercic, D. Tuckovic, N. Crnomarkovic, A numerical study of a utility boiler tangentially-fired furnace under different operating conditions, *Fuel, 87*, 2008, pp. 3331-3338.

[10]. G. Tang, B. Wu, K. Johnson, A. Kirk, C.Q.Zhou, Simulation of an industrial tangentially fired boiler firing metallurgical gases, *Journal of Thermal Science and Engineering Applications*, ***7****(1)*, Paper No: TSEA-13-1204; 2014.

[11]. R.V. Filkoski, Pulverised-Coal Combustion with Staged Air Introduction: CFD Analysis with Different Thermal Radiation Methods, *The Open Thermodynamics Journal, 4*, 2010, pp. 2-12.

[12]. N. Hashimoto, R. Kurose, H. Tsuji, H. Shirai, A numerical analysis of pulverized coal combustion in a multiburner furnace, *Energy Fuels, 21*, 2007, pp.1950-1958.

[13]. R. Kurose, H. Makino, A. Suzuki, Numerical analysis of pulverized coal combustion characteristics using advanced low-NO_X burner, *Fuel, 83*, 2004, pp.693-703.

[14]. R. Kurose, M. Ikeda, H. Makino, Combustion characteristics of high ash coal in a pulverized coal combustion, *Fuel, 80*, 2001, pp.1447-1455.

[15]. R. Kurose, H. Tsuji, H. Makino, Effects of moisture in coal on pulverized coal combustion characteristics, *Fuel, 80*, 2001. pp. 1457-1465.

[16]. R. Kurose, H. Watanabe, H. Makino, Numerical simulations of pulverized coal combustion, *KONA Powder and Particle Journal, 27*, 2009. pp. 144-156.

[17]. D. Cvjetinović, A. Erić, P. Škobalj, Garancijska ispitivanja kotla TE TUZLA blok 6, *Tehnički izvještaj NIV-LTE 533*, Institut za nukelarne nauke Vinča, 2013.

[18]. M. Hadžikadić, S. Avdaković. (eds), The Causes and Consequences of Deficit in Nominal Temperature of Reheated Steam After Implementation of Primary Measures for NO_X Reduction on the Boiler OB-650, *Advanced Technologies, Systems, and Applications II*, 2017. pp. 1147-1155.

[19]. C.J. Davis, P.J. James, L.W. Pinder, A.K. Mehta, Effects of fuel composition and combustion parameters on wall fireside corrosion in pulverised coal-fired boilers, *Materials Science Forum, 369-372*, 2001, pp. 857-864.

[20]. L.I. Diez, C. Cortes, A. Campo, Modelling of pulverised coal boilers: review and validation of on-line simulation techniques, *Applied Thermal Engineering*, *25*, 2005, pp. 1516-1533.

[21]. S. Wenjing, Z. Wenqi, Y. Aibing, L. Longhai, Q. Yujun, Numerical investigation on the flow, combustion and NO_X emission characteristics in a 660 MWe tangential firing ultra-supercritical boiler, *Advances in Mechanical Engineering 8(2)*, 2016, pp. 1-13.

[22]. A. Fande, P.V. Joshi, S. Gabhane, M.K. Sahu, CFD Investigation of Combustion in 660MW Tangential Fired Boiler, *International Journal of Engineering Research & Technology (IJERT), 3(1)*, 2014, pp. 892-908.

[23]. A. Mešić, *Numeričko modeliranje strujanja aerosmjese u kotlovskom postrojenju*, Master thesis, Faculty of Mechanical Engineering, University of Tuzla, Tuzla, 2017.

[24]. ANSYS Inc. *ANSYS Fluent User Guide*, ANSYS Inc.: Canonsburg, PA, USA, 2016.

[25]. G. Sankar, D.S. Kumar, K.S. Balasubramanian, Computational modeling of pulverized coal fired boilers–a review on the current position, *Fuel*, *236*, 2019, pp. 643–665.

[26]. R. V. Filkoski, L.J. Bureska, I.J. Petrovski, Assessment of the Impact of Under-Fire Air Introduction on the Pulverised Coal Combustion Efficiency, *Chemical Engineering Transactions, 34*, 2013, pp. 25-30.