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Numerical Study of Optimal Combustion in Tangentially Fired Coal Boiler 625 MW by Considering Rear Pass Temperature

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Abstract.
Tangentially fired boilers have a burner system within a single actuator group and a SOFA system that controls the fuel and air distribution to generate boiler combustion in the furnace. The goal of this study was to determine optimal combustion by statistically examining the effect of changes in the burner and SOFA angles on the response of rear pass boiler temperature and NOx concentration in tangentially burned boilers. (1) Tilting burner angles of $+30^0$, $+15^0$, 0^0, -15^0, and -30^0, and (2) SOFA tilting and yawing angles of -15^0, -8^0, 0^0, $+8^0$, $+15^0$ were used in this study. The GA (Genetic Algorithm) approach and CFD software were utilized to optimize the rear pass temperature and NOx content response. The simulation results data were then examined using ANOVA, and it was discovered that tilting burner and tilting SOFA have a substantial effect on response, however, yaw SOFA does not. In this scenario, the resulting angle variations for tilting burner, SOFA-tilt, and SOFA-yaw are $+11^0$, -15^0, and 2^0, respectively. The optimal angle adjustments result in rear pass temperatures of 821.33 ^{0}K and 816.27 ^{0}K, with a slight fluctuation of 5.06 ^{0}K. This was in contrast to the preceding conditions, when the rear pass temperatures of sides A and B were 781.32 ^{0}K and 767.83 ^{0}K, respectively, resulting in a 13.49 ^{0}K difference.

Keywords: tilting burner, tilting and yawing SOFA, rear pass temperature, NO_x, GA and CFD method

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1. INTRODUCTION

High-tech plants are highly efficient and often considered as advantageous due to advanced technology. This efficiency leads to a reduction in the cost of electricity generation, resulting in cheaper prices for consumers. Moreover, these plants emit fewer pollutants during operation, making them more environmentally friendly. However, the introduction of high-tech plants can pose a threat to existing systems that rely on outdated technology. In 2011, a deviation in the temperature of the rear pass on sides A and B was observed during the operation of a 625 MW capacity coal-fired power plant, as reported in the COD (Commercial Operation Date). This deviation highlighted the influence of certain boiler parameters on the combustion process and heat absorption, specifically the inclination angle of the burner [6].

PLTU is one of the technologies highly considered due to its environmental effects, regarding its contribution to global warming and pollution gas emissions. From this context, NO_x is one of the emitted gases influencing the environment and human health. This leads to the consideration of several technologies, to reduce and control the formation of NO_x emissions, such as the use of OFA (Over Fire Air) [16]. Based on NO_x formation in 500 MWe tangential-fueled boiler, numerical method was implemented, leading to the provision of a useful basis for the reduction and control of gas [1].

A 600 MW down-fired boiler also comprehensively evaluated the influence of SOFA angle on flow, combustion characteristics, and NO_x emissions, for the new burning system with numerical simulations and on-site experiments. The simulation showed that a significant reduction in NO_x was obtained for all five corners of SOFA, compared to the original combustion system [5].

In a previous study emphasizing rear pass temperature boiler influenced by tilt burner angle of LRC and MRC coal conditions on tangential boiler, ANSYS FLUENT software and the BPNN-GA (Back Propagation Neural Network-Genetic Algorithm) method were employed to determine its optimization [17]. Therefore, this study aims to determine the operating parameters of tilt burner angle, as well as tilting and yawing SOFA, to minimize boiler rear pass temperature and NO_x content. In this study, the varied parameters are tilt burner angle, as well as tilting and yawing SOFA. GA (Genetic Algorithm) method is also used to determine the response settings of rear pass temperature and NO_x content under optimal conditions. Numerical studies using CFD software are subsequently carried out on the obtained level, to determine the distribution of temperature and NO_x content at optimal conditions.

2. METHODOLOGY/ MATERIALS

Burner was a supply of fuel and air into boiler to be burned in the furnace, with the geometry designed to produce optimal combustion. From this context, tangentially-fired boiler was equipped with tilting burner facilities, which enabled simultaneous movement in one actuator group. Combustion OFA was also a process in the primary burning zone, using an air supply less than the theoretical parameter needed. The remaining air was then injected into combustion chamber through OFA. Moreover, two types of OFA were observed In tangentially-fired boiler, namely (1) CCOFA (Close Coupled Over Fire Air) implemented a similar wind box for the main combustion atmosphere, with the port being adjacent to the arrangement Burner, (2) SOFA (Separated Over Fire Air) used a separate wind box having a relevant burner. The port was also separated by several distances from burner array. From these descriptions, the addition of SOFA system enabled better gradual combustion, leading to the sole adjustment of the location and distribution from the revamped air. This system was vertically or horizontally arranged at the same angle, as vertical and horizontal settings affected NO_x and CO level controllers. Horizontal settings are also capable of reducing the O_2 imbalance at the outlet. Based on the investigation of large-scale, advanced low NO_x gas temperature deviations in tangentially-fired powder coal boiler, SOFA was observed as an effectively adjustable operating parameter [7].

GA was a search technique and optimization technique capable of mimicking the process of evolution and changes in the structural patterns of living things. The main tenets emphasizing the work patterns of this algorithm were inspired by natural selection and the principles of genetic science [15].

GA method was used to obtain settings for tilt burner, as well as tilting and yawing SOFA boiler angle with LRC coal calorific value. This was to balance or optimize temperature deviation of left and right-side boiler, as well as minimize rear pass temperature, and NO_x content. To determine the distribution of temperature and NO_x content, numerical simulation method was implemented through CFD software, to model and simulate optimal conditions. Research Method Flowchart shown in Figure 1.

In this study, boiler combustion was stimulated with tilt burner angle of -30^0, -15^0, 0^0, +15^0, and +30^0, as well as tilting and yawing variations of -15^0, -8^0, 0^0, +8^0, and +15^0 in LRC coal conditions.

3. RESULTS AND DISCUSSIONS

Based on the results, the simulated data were validated to ensure that the simulation model made was similar to the actual condition of the equipment. This validation process was carried out in several previous studies [17], with the operational data emphasizing the performance test information on December 19, 2017, at 09:40–11:40 WIB. This was appropriately conducted with a stable unit load at 504 MW.

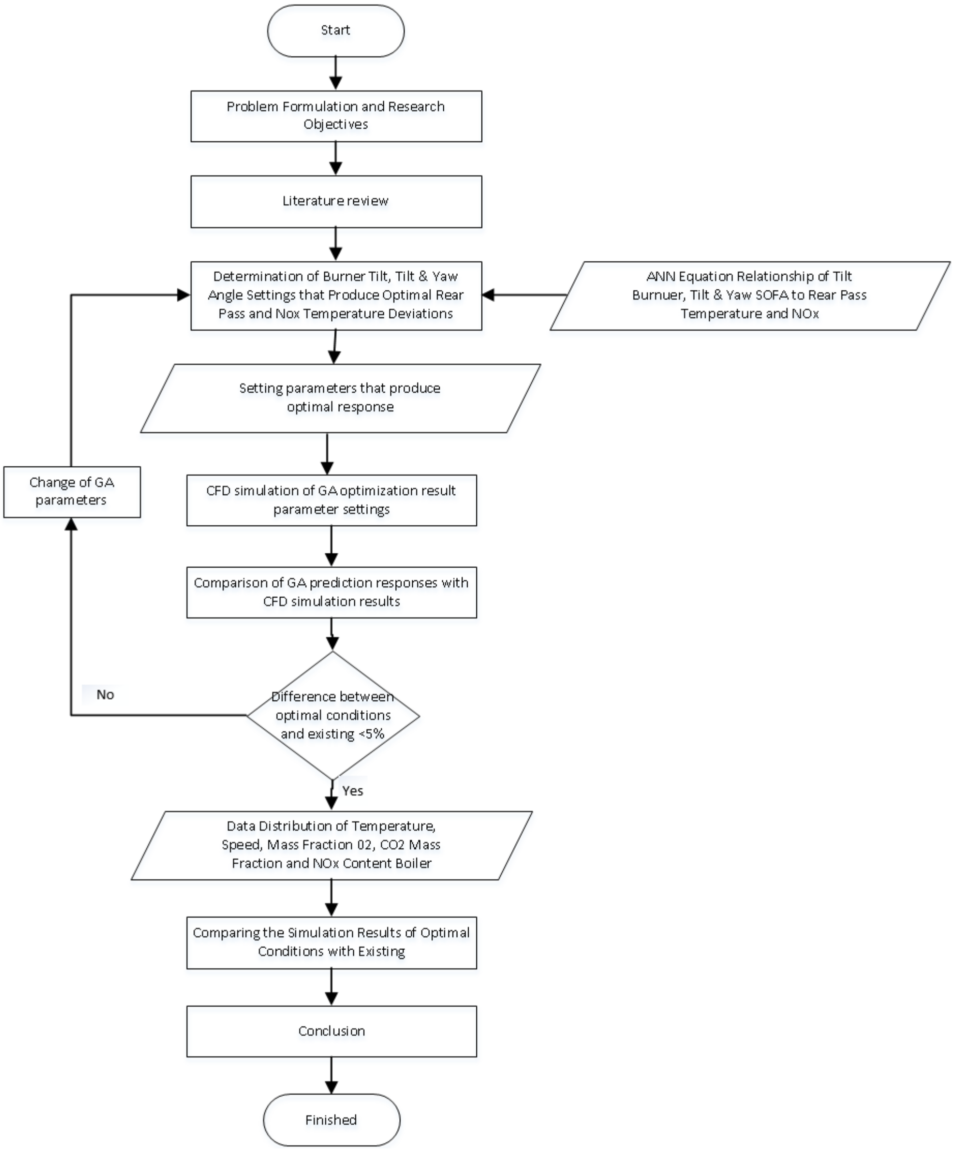

Figure 1: Research Method Flowchart.

3.1. ANN Training and Graph Equation Prediction

ANN training and graph equation prediction were carried out before obtaining angular variations with optimal rear pass temperature deviations. This was carried out to determine function equations and visualize the graphical relationship of factors to responses.

3.1.1. ANN Training

ANN training was carried out on each target after obtaining the significance of the factor to the response, to obtain a function equation with an MSE value close to 0, as shown in Table 1.

TABLE 1: Anova Test Results in Factor Determination.

Function	MSE	Amount of Hidden Layer	Sum Neurons
ΔT rear pass	0.0016	1	6
NO_x	0.141	1	10

3.1.2. Graph Equation Prediction

The function equation was visualized after being obtained through ANN training, by predicting the graphical expression of the factor-response relationship. This prediction emphasized the relationship between tilt burner and SOFA tilting angle to rear pass temperature deviation, NO_x, and boiler exit temperature variation, as shown in Figures 2 and 3.

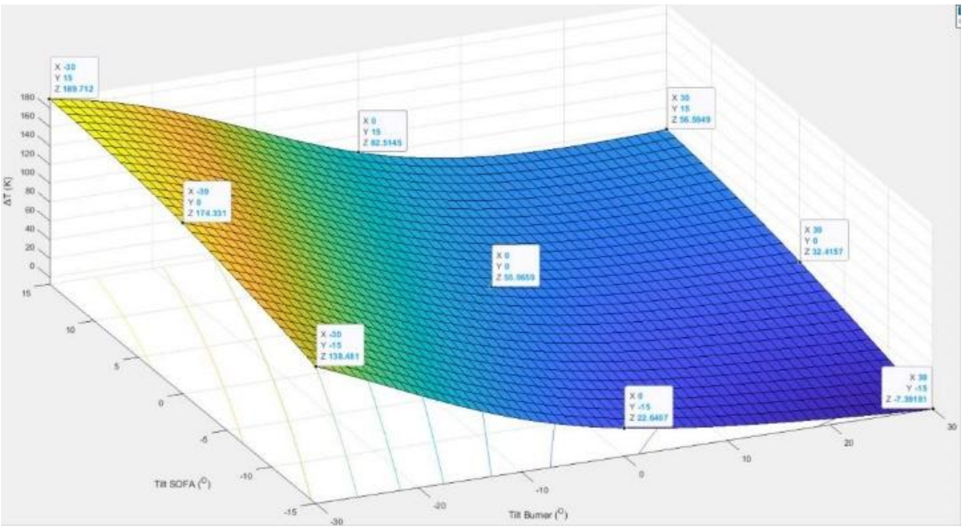

Figure 2: Rear Pass Temperature Deviation Chart Prediction.

Based on Figure 2, the lowest rear pass temperature deviation had tilt burner and SOFA angle of 0^0 and -15^0 at 22.64 ^{0}K, respectively. This condition was caused by changes in residual swirl combustion flow, due to the velocity adjustments in tilt angle of SOFA.

In Figure 3, NO_x Content had tilt burner and SOFA angle of -30^0 to $+30^0$ and -15^0 to $+15^0$, with similar graphic contours, respectively. At tilt SOFA angle of $+15^0$, a higher value

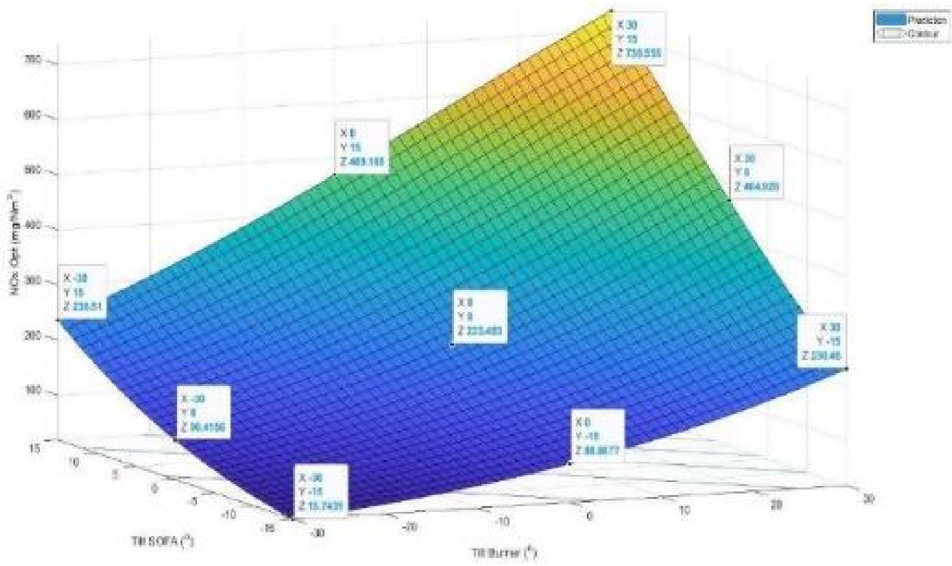

Figure 3: NO_x Content Graph Prediction.

was produced, compared to the coefficient at -15^0. This was due to the accumulation of NO_x content, which occurred from the lower to the upper elevation of combustion chamber.

3.2. Optimization of Boiler Rear Pass Temperature to Tilt Burner, Tilt SOFA, Yawing SOFA

Based on the factor-response simulation, 2 variables significantly affecting temperature deviation conditions of sides A and B were observed, namely tilt burner and SOFA factors. This was accompanied by the optimization simulation carried out by using GA method, to obtain\optimal position in setting tilt angle. It also emphasized the achievement of a minimal deviation value at boiler rear pass temperature.

From the results, 3 functions were jointly optimized with GA, namely (1) Delta Temperature from sides A and B, (2) Delta temperature side A with boiler design temperature, and (3) Delta temperature side B with boiler design temperature. These elements were optimized in one objective function with a predetermined weight. The following prioritizes the scripts for objective function and GA in MATLAB software,

- Script for objective function

```
function y=objfunc1(x)
T=TempFcn(x');
obj1=T(1,1)-T(2,1); %Delta T as objective function one
```

obj2=T(1,1)-813; %Difference between *temperature* on side A and *boiler* design *temperature*

obj3=T(2,1)-813; %Difference between *temperature* on side B and *boiler* design *temperature*

w1=1; %weights for OBJ1

w2=1; %weights for OBJ2

w3=1; %weights for OBJ3

y=w1*abs(obj1)+w2*abs(obj2)+w3*abs(obj3);

End

- Script for GA

Clear

CLC

input=xlsread('WAD.xlsx',2,'C5:E30'); output=xlsread('WAD.xlsx',2,'F5:G30')

numvariable=3;

mininput=min(input);

maxinput=max(input);

minoutput=min(output);

maxoutput=max(output);

IntCon=[1 2 3];

[x,fval]=ga(@objfunc1,numvariable,[],[],[],[mininput],[maxinput],[],IntCon) %-1 lower bound of normalization, 1 upper bound of normalization

T=TempFcn(x');

TA=T(1,1)

TB=T(2,1)

DeltaT=TA-TB

Based on the optimization simulation, the following was observed Angle Optimization Results on table 2.

TABLE 2: Angle Optimization Results.

Factor	**Angle (^{o})**
Tilt Burner	11
TILT SOFA	-15
Yawing SOFA	2
ΔT	2.0887

To provide the angle setting and achieve the smallest ΔT value, GA method was employed. This indicated that the predicted values for rear pass temperature were 813.7958 ^{0}K and 811.7071 ^{0}K on sides A and B of boiler, leading to ΔT (Delta Temperature) of 2.0887 ^{0}K, respectively. Based on the MATLAB software optimization, the angle obtained for burner, as well as tilt and yaw SOFA were 11^0, -15^0 and 2^0, respectively. This led to numerical simulations on Ansys software, which produced rear pass temperature of 821.33 ^{0}K and 816.27 ^{0}K on sides A and B of boiler, leading to a deviation of 5.06 ^{0}K, respectively. At the optimization angle that produced low-temperature deviations, the distribution conditions were more even on sides A and B. This was not in line with the existing situations having 781.32 °K and 767.83 °K on sides A and B, with a small deviation of 13.49 °K.

Table 3 show Response Parameters of Existing Variations and Optimization Variations of Numerical Simulation Results.

Table 3: Response Parameters of Existing Variations and Optimization Variations of Numerical Simulation Results.

Trial	Factor Parameters			Response Parameters			
	Tilt Burner (°)	SOFA *TILT* (°)	Yaw SOFA(°)	A Side (°K)	B Side (°K)	ΔT (°K)	NO_x (mg/Nm^3)
1	0	0	0	781.32	767.83	13.49	163.46
2	11	-15	2	821.33	816.27	5.06	188.87

While Figure 4 shows Temperature Distribution in the Inlet Area of the Backpass Boiler.

3.3. Analysis of Optimization Results

Analysis was carried out on several combustion parameters, including temperature distribution, O_2, CO_2, and NO_x contours, as well as velocity. This was carried out by comparing various numerical simulations.

3.3.1. Temperature Analysis and Contour Analysis of O_2 Mass Fraction

In a very hot combustion chamber, the coal (fuel) emanating from burner nozzle immediately reacted with the oxygen from primary air or secondary water, to achieve a burning process. This led to the production of heat, which was then transferred to other parts of boiler.

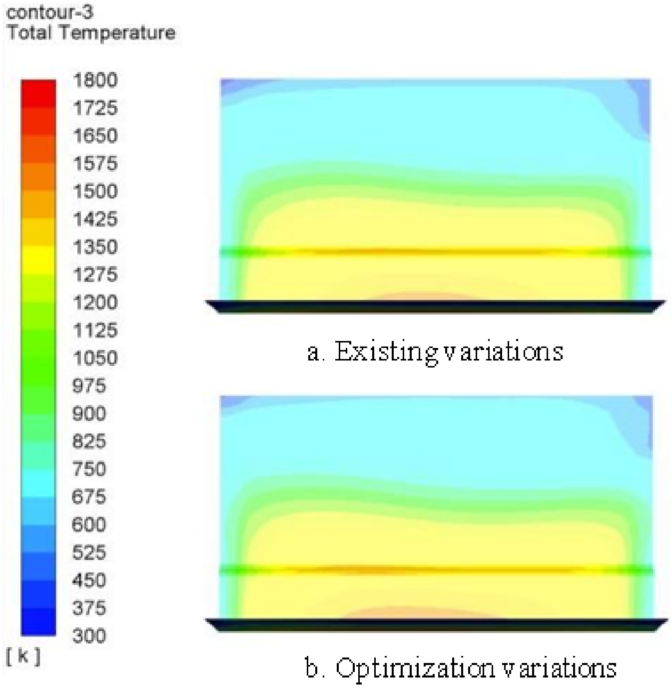

Figure 4: Temperature Distribution in the Inlet Area of the Backpass Boiler.

To determine an overview of temperature distribution, vertical data were obtained at the centre boiler. Figure 5 shows the heat distribution in boiler, which was between 300–2300 ^{0}K. In this case, the red and blue colours represented higher and lower temperature levels, respectively.

In Figure 5, tilting angle position in both variations affected temperature in the superheater and reheater areas. When increasing the deviation angle of rear pass temperature optimization burner by +11^0, as well as adjusting tilt and yaw SOFA angle to -15^0 and +2^0, respectively, an elevation was observed in the orange area. From this context, the colour map indicated that temperature in the orange area was significantly higher than those in the yellow area, especially in the 0^0 position. This demonstrated that the fireball was adjusted upwards when tilting burner angle was raised, leading to a shift in the incoming heat in the superheater and reheater areas. In the furnace exit area, the orange colour illustrated the existence of combustion reaction to coal powder on SOFA layer. Moreover, the direction of airflow in the CCOFA and SOFA was opposite to the route of the primary and secondary air movement. This led to the development of turbulence, where combustion chamber hot air was more evenly distributed. Another function of the opposite airflow direction was to reduce or eliminate the tail of the fireball, preventing it from reaching the superheater area. In the bottom boiler area, green and blue colours were more dominant, proving the absence of coal powder combustion. However, heat absorption was observed in the water wall zone.

Subsequent observations were conducted at each elevation of the coal burner, CCOFA, SOFA, and furnace exit, as shown in Figure 5.

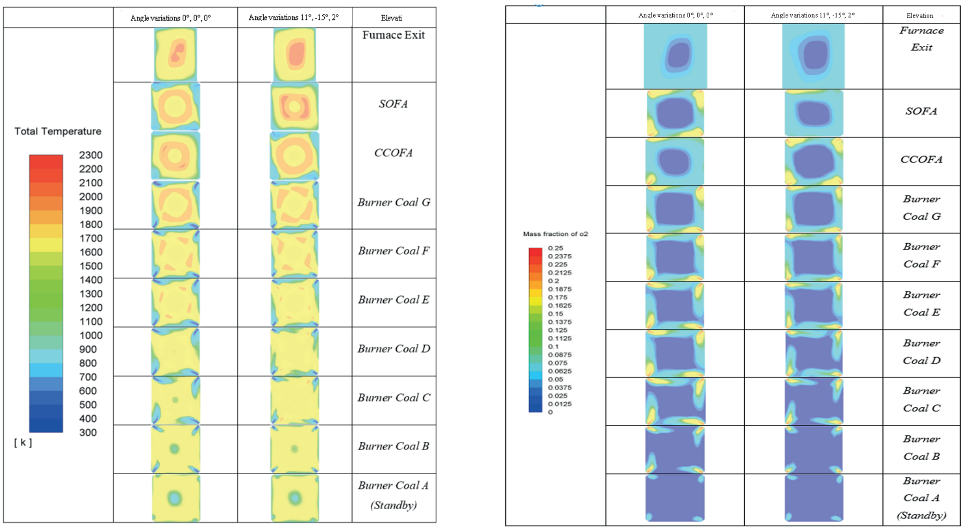

Figure 5: Temperature & O_2 Distribution per Boiler Burner Elevation.

Based on Figure 5, temperature distribution of each boiler burner elevation was observed. This indicated that the two variations were almost similar, with higher elevation leading to dominant orange and red colours. From these colours, combustion process increased with the mixture of coal powder and more homogeneous hot air. Meanwhile, the distribution of new orange and red colours was observed at the upper elevation of burner, compared to tilt angle position of 0^0. The produced fireball pattern was also identical to tilt burner angle position of 0^0.

To analyze combustion process, the mass fraction of O_2 was conducted. In this case, the data collection process was carried out in the vertical and horizontal cross-sections of the coal burner. Figure 5 shows the contour of O_2 in the vertical cross-section of boiler.

Based on Figure 5, the edge of combustion chamber area had a larger mass fraction of O_2 than in the fireball section. This indicated that the oxygen entering combustion chamber was not immediately exhausted to oxidize the coal powder particles. In this case, the lack of oxygen on the edge of the fireball was capable of causing incomplete combustion, leading to the production of CO and non-optimal heat. From the optimization angle variations, the O_2 distribution shifted with the increased upward adjustment of the fireball due to tilting.

In burner area, a noticeable increase was observed in oxygen content from layers A to G. This was affected by low-quality coal, requiring a longer time to burn completely.

When the coal used was lower than the design, passage in combustion chamber became insufficient for the occurrence of complete burning.

Based on the CCOFA and SOFA layers, a lighter colour change was observed in each corner. This was because the area was supplied with a considerable amount of air from the CCOFA and SOFA nozzles.

3.3.2. NO_x Contour Analysis

Based on the ANOVA test, the selected factor did not significantly affect the response of NO_x content. However, observations were conducted on NO_x mass fraction contour, to analyze the process of its exhaust air formation from the furnace area to the exit flue gas. Figure 6 shows Effect of Angular Variation on NOx Contour in Boiler

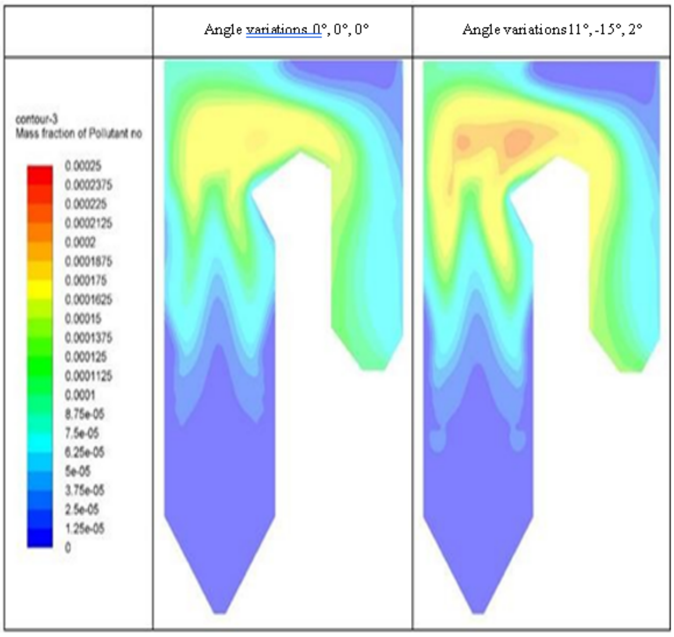

Figure 6: Effect of Angular Variation on NO_x Contour in Boiler.

4. CONCLUSION

Based on the obtained results, several conclusions can be drawn. Firstly, the application of the GA method for optimization yielded specific angles that are suitable for actual operational conditions. The optimal *angles* for the *burner*, as well as the *tilt* and *yaw* angles for the SOFA, were determined as +11°, -15°, and 2°, respectively.

Temperature distribution showed that the *average* heat values in the *furnace* area produced 1599.12°K and 1544.17°K at optimal and existing variations, respectively. This emphasized an increase of 4% when compared to the existing *angle* variation conditions.

From the ANOVA test, the selected factor did not significantly affect the response of NO_x content. This indicated that the largest NO_x *content* at boiler *outlet* was the optimization variation of 188.87 mg/Nm3, compared to the existing value of 163.46 mg/Nm3.

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