Numerical Investigation of Over Fire Air (OFA) Effect on Flow Characteristics, NOx Combustion and Emission in a 600 Mw Tangentially Fired Pulverized Coal Boiler

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***Abstract*— One of the coal-fired air emissions in boilers is NOx, which has a significant impact on the environment and could cause acid rain, ozone formation, visual impairment and health problems in humans. There are several technologies to reduce and control the formation of NOx emissions, which one of these technologies is the use of over-fire air (OFA). In this research will observe the effect of overfire air (OFA) usage and analyze by numerical 3D modeling method using computational fluid dynamics (CFD) in Paiton 9 power plant boiler and analyzed for 5 (five) OFA damper opening variations, i.e 0%, 25%, 50 %, 75% and 100%. This research will analyze several factors that have significant influence on NOx emission formation, that are: the temperature distribution of the boiler during the combustion process, the distribution of nitrogen oxide (NO) and carbon dioxide (CO2), direction of flue gas flow and trajectory of coal particles and residence time indicating the length of time of burning. The results showed that the lower the flame temperature, the smaller the formation of NOx; the smaller the oxygen content in the combustion process, the smaller the formation of NOx; the shorter the residence time of combustion products in the high temperature zone the smaller the formation of NOx, and the smaller the nitrogen content in coal, the smaller the formation of NOx.**

***Keywords*— Coal Combustion Gas Emission, Combustion Simulation, Over-Fire Air (OFA), Tangentially Fired Boiler**

I. INTRODUCTION

The combustion air system in the boiler consists of primary water that functions as air fluidization and is used as combustion air, whereas secondary air is a special air used for combustion and is fed at a certain height from the furnace [1].

The principle of coal combustion process is the process of oxidation of organic material contained in coal, where the combustion process consists of 3 (three) stages [2], namely: devolatilization, is the initial phase of particle warming, where due to the increase in temperature the coal will break into 3 (three) components, namely gas, char and tar. At temperatures of 1800 to 1900 K, volatile materials began to release and burn quickly. Furthermore, oxidation char is a heterogeneous combustion process of solid core (char) after the release of the gas component. The oxidation of char and the release of volatile matter occur simultaneously and can be said that the oxidation of char is a slow process of devolatilization. The last stage is volatile reaction. The process of volatile combustion is a type of homogeneous gas-phase combustion at a temperature of around 1173 K. Volatile matter is an organic element which is in the form of gas or vapor during the heating process of coal which consists of several different hydrocarbons, including CO, CO2, H2O, methane, ethane, ethylene and tar.

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The combustion process in the boiler produces nitrogen oxide (NOx) emissions, where the NOx emission value is determined by the working temperature and the amount of oxygen and nitrogen in the fuel and air. There are 2 (two) types of the most dominant NOx formation processes, namely Thermal NOx and Fuel NOx [3].

Thermal NOx is the process of forming NOx derived from nitrogen contained in combustion air. When the combustion temperature reaches 1204 °C, the nitrogen (N2) and oxygen (O2) molecules contained in the combustion air will be split into their constituent atoms, namely: N2 and O2 atoms. Then these atoms will react to form NO bonds and turn into NO2 in the further oxidation process. The process of nitrogen oxidation can be shown in the chemical equation below [2].

$$O + N_2 \leftrightarrow NO + N;\ N + O_2 \leftrightarrow NO + O$$

Fuel NOx is the process of forming NOx derived from nitrogen contained in coal fuel, either in volatile matter or char. It is assumed that 90% of the nitrogen contained in volatile matter will turn into HCN, while the rest will turn into NH3 [4].

NOx emissions have a significant impact on the environment, namely the formation of ozone, visual disturbances and health problems in humans. Considering the impact of NOx emissions, efforts should be made to reduce and control the NOx emissions generated from coal burning in boilers, by applying several technologies such as: modification of burner design, flue gas recirculation and over fire air (OFA) utilization. The main purpose of the technology is to minimize reaction temperature and contact between nitrogen in coal and oxygen in combustion air, and to form fuel-rich zone, thus reducing NOx formation.

II. METHOD

A. Numerical analysis

The parameters used in performing this calculation are operating parameters of PLTU Paiton 9, presented in detail in Table 1.

B. Numerical models

Basically, the function of separated over-fire water (SOFA) is to control the emission of NOx which is a combustion product between coal and combustion air in the boiler. This research is done by making some numerical simulation that varied against OFA damper opening position, that is 0%, 25%, 50%, 75% and 100%. There are 2 (two) kinds of simulation results taken, the first is qualitative data in the form of visual observations based on the contours of temperature distribution, CO_2, NOx and velocity profiles, and quantitative data in the form of actual values at the measurement points presented in table form and chart.

Numerical calculations are performed based on a finite volume approach where computational domains are divided into control volume through computational mesh [5], on all parts of the boiler, including combustion zone, furnace, superheater, re-heater, rear pass, LTSH and economizer, as shown in Figure 1. All parts of the heat exchanger, including the superheater, re-heater, and economizer are considered porous media. Mesh system consists of 680.104 cells.

III. RESULT AND DISCUSSION

A. Validation

In order to know the accuracy of the simulation result using commercial computational fluid dynamic code, it is necessary to validate by comparing the actual condition of the performance test unit conducted in June 2012 against the simulation result and then calculated the error value. The measurement points used for validation are the inlet & outlet side of LTSH, and the outlet economizer side. The temperature data of the numerical simulation result is the average value of the temperature at the iso-surface cross section of each measurement point. Comparison of actual values and simulation results can be shown in Figure 2.

It shows the graph of temperature drop from the LTSH inlet to the economizer outlet, both for performance test data and numerical simulation result data. The trend or decrease in temperature indicates the absorption of exhaust heat by 2 (two) parts of heat exchanger, namely low temperature superheater and economizer. It appears that the temperature data of the simulation results do not vary much with the actual performance test data, the error value is within the tolerance limit of ± 5%, so the simulation study of OFA damper openings on the variation OFA 0%, 25%, 50%, 75% and 100 % can be continued.

B. Temparature distribution

This section will present the results of qualitative and quantitative numerical simulation analysis with the observation area including the fire burner and OFA damper which is the injection part for fuel and combustion air, furnace (outlet), heat exchanger (superheater part, re-heater and economizer), and boiler outlets. Observations were made by making iso-surfaces on elevation of coal burners, OFA dampers and furnace outlets to determine horizontal cross section temperature distribution.

Figure 3 shows the temperature distribution in the vertical section of the boiler for each variation of OFA damper opening. In the combustion zone to the area furnace is a section with the highest heat distribution which is characterized by an orange distribution. Overall, the temperature distribution contour shows the increase in the total temperature starting from the variation of OFA 0% to OFA 75%, which is characterized by an increase in orange area. At the temperature distribution contour variation OFA 100% shows a slight decrease in temperature. At the top of the furnace area, especially in the OFA area, the orange color is evenly distributed, and maximum conditions are reached and homogeneous mixing occurs between the fuel and combustion air, which is affected by the addition of combustion air through a separated over-fire water (SOFA). In this section will present the results of quantitative numerical simulations that will be displayed in tables and graphs.

Figure 4 shows the rise in temperature as the increase of OFA damper opening from 0% to 75%. If OFA damper opening is more than 75% then temperature will tend to decrease. This is likely because the addition of combustion air makes the composition of the fuel and combustion air not homogeneous so that complete oxidation does not occur. From the graph above also shows the decrease of temperature from elevation over-fire air to furnace outlet. This shows the absorption of heat by the wall tube.

C. Nox Distribution

The NOx distribution contour in the boiler's vertical cross section as shown in Figure 5. below, where from the visual observation can be seen the NOx formation process for each variation of OFA. In the variation of OFA 0%, the area of dark blue is bigger than the contours of other OFA variations and tends to shrink along with the addition of OFA dampers. This indicates the effect of the addition of combustion air causes an increase in NOx content. In the heat exchanger and back-pass area it shows a reddish yellow color which indicates that NOx formation still occurs. The largest NOx mass fraction occurs in variations of OFA 75%, because in these variations the highest temperature increase occurs. Then the NOx mass fraction will decrease as the temperature decreases in the OFA variation 100%. To know the effect of the addition of combustion air through increased aperture of OFA damper can be shown in Figure 6.

From the graph shows that the addition of combustion air through increased OFA damper up to a certain extent affect the increase of NOx mass fraction. When OFA is 100%, the value tends to decrease because it correlates with a decrease in combustion temperature. On the wall side the speed is minimum because of the resistance of the wall and the speed will increase in areas far from the wall [6].

D. Quantitative Analysis of CO2 Distribution

Quantitative analysis of CO_2 distribution uses CO_2 mass fraction data for each observation elevation. The data shows a tendency to increase the CO_2 mass fraction along with the elevation of the measurement point. At the elevation of coal burner A to coal burner C the value fluctuates up and down which indicates that at the elevation of coal burner A to C there has not been a mixture of fuel and homogeneous combustion air so that the CO_2 value is low. After the elevation of coal burner C, the mass fraction of CO_2 tends to rise, which means that there has been a homogeneous mixing of fuel and combustion air so that CO_2 production increases.

E. Quantitative Analysis of CO Distribution

Analysis of CO distribution data is used as an indication of complete combustion. The amount of CO is inversely proportional to the value of CO_2, where the smaller the CO value, the greater the value of CO_2 and the more complete combustion.

The CO mass fraction decreases when the variation of OFA is 0% to OFA 75%, and tends to increase in the variation of OFA 100%. This is due to the combustion process in variations of OFA 0% to 75% better than the combustion process in the variation of OFA 100%.

IV. Conclusion

Quantitative data of numerical simulation results as describe in Table 2 show the addition of combustion air by varying the OFA damper from OFA 0% to OFA 75% influences the temperature increase from 1,551.99 K to 1,680,09 K or by 8%. This indicates that the addition of combustion air can improve the combustion process. In variations of OFA 100% addition of combustion air is no longer effective for oxidation. Other indications are a decrease in the CO mass fraction and an increase in the mass fraction of CO_2, which implies that the mixing of hydrocarbons and oxygen has been homogeneous so that the combustion results are mostly in the form of CO_2. At 100% OFA condition, since all hydrocarbons and CO have been oxidized, the addition of combustion air which has a temperature of 612 K, will absorb the combustion heat at a temperature of about 1600 K, resulting in a decrease in temperature from 1,680.09 K to 1,606, 66 K or about 4 %.

Based on the fact that the burning temperature conditions are quite high above 1400 K, it will form NOx. The content of NOx will rise along with the increase in temperature, so that when OFA 0% to OFA 75% there is a significant increase of NOx, which is 12%. Then with a decrease in temperature at 100% OFA, NOx content also decreased by 7% compared to 75% OFA. This shows that OFA serves to reduce NOx emissions. The incoming air of OFA is no longer used for oxidation because the hydrocarbon content has run out. OFA with a temperature lower than the combustion temperature will absorb the combustion heat so that the combustion temperature drops and NOx emissions are also decreased. The data of numerical simulation results for the distribution of CO_2 and CO supports the phenomenon.

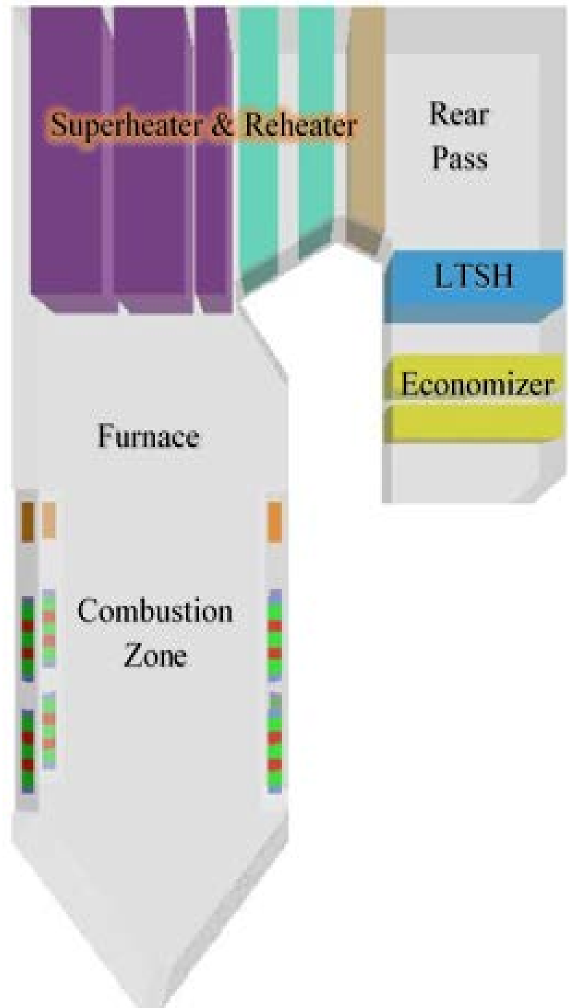

Figure 1. Schematic configuration of tangentially fired pulverized-coal boiler.

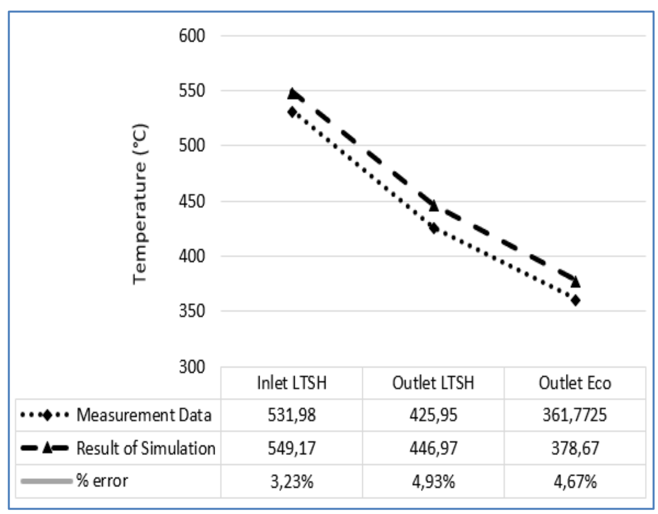

Figure 2. Comparison graph of actual values and numerical simulation results.

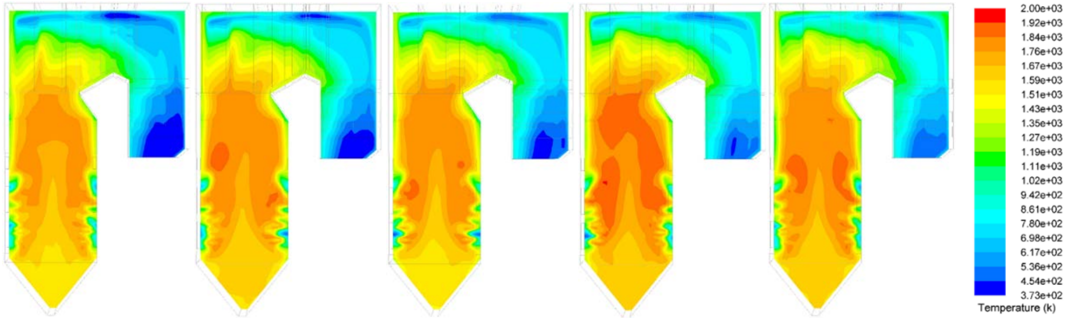

Figure 3. Contour of temperature distribution vertical boiler section

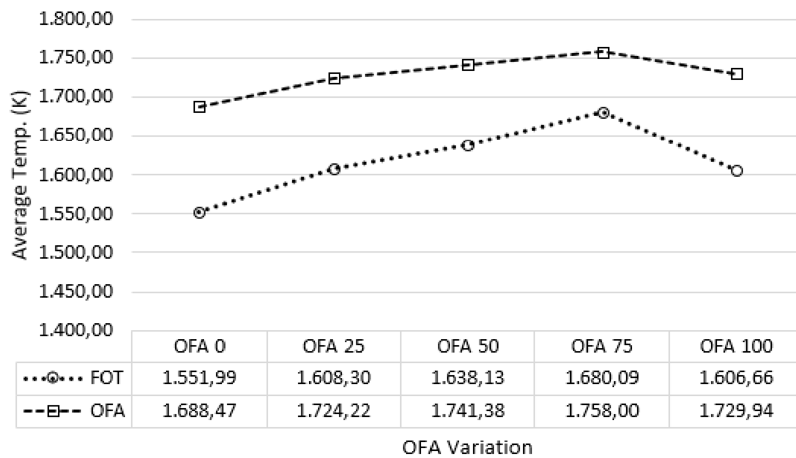

Figure 4. Average temperature of over-fire air and furnace outlet cross section.

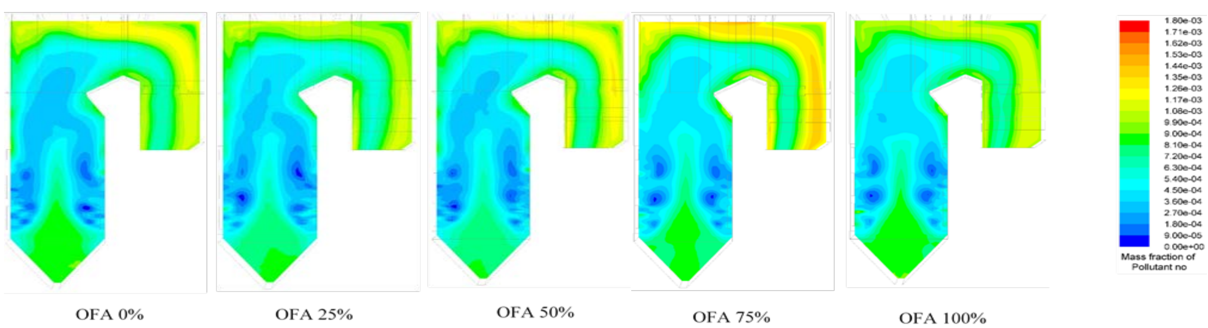

Figure 5. Contour of Nox Distribution

TABLE 1.
OPERATION PARAMATERS OF POWER PLANT

Parameters	Unit	Value
Coal feeding rate	kg/hr	367,350
Steam generation rate	kg/hr	2,099,850
Secondary air flow	T/hr	1,919.21
Secondary air temp.	°C	339.49
Primary air flow	T/hr	836.22
Primary air temp.	°C	61.04
Coal Ultimate Analysis (DAF)		
Ash	%	2.90
Moisture	%	33.00
Carbon	%	43.59
Hydrogen	%	3.1
Nitrogen	%	0.89

Oxygen	%	15.28
Sulphur	%	0.24
Calorific value (LHV)	kCal/kg	4,270
Coal Proximity Analysis (ADB)		
Moisture	%	17.00
Ash	%	3.90
Volatile matter	%	48.29
Fixed carbon	%	30.80

TABLE. 2.
QUANTITATIVE DATA OF NUMERICAL SIMULATION RESULTS

Parameter	**Sat.**	**Furnace Outlet**				
		OFA 0%	**OFA 25%**	**OFA 50%**	**OFA 75%**	**OFA 100%**
Temperature	K	1.551,99	1.608,30	1.638,13	1.680,09	1.606,66
CO	%	0,00107	0,00105	0,00035	0,00020	0,00037
CO_2	%	20,493	21,361	21,427	21,576	21,399
Nox	%	0,0536	0,0551	0,0695	0,0601	0,0560

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