Numerical Simulation of Combustion Characteristics on Tangentially Fired Boiler with Different Yaw Angle

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Abstract: Coal is one of the energy sources that widely used for electricity. Nonetheless, the high demand for coal is not comparable with the remaining coal in the world, so it is necessary to make a study to reduce the consumption rate of coal. Increase the efficiency of the tangentially fired boiler with improvement in the burner is one of the right options. In some cases, because of the uneven distribution of coal type, blended of mixing coal of higher and lower rank coal is necessary. This condition will affect the combustion behavior in the boiler, also emission production. This research will study the effect of yaw angle modification to combustion behavior and emission analysis in the tangentially-fired boiler with the condition of fuel 30% MRC and 70% LRC. Computational fluid dynamics has been used in this study with validation. The yaw angle diverse from +5º, 0º, -5º, -10º, dan -15º. The results show that the wider yaw angle increases the temperature deviation and NOx concentration. Coal burner with -5º has the least temperature deviation and the lowest NOx emission, which has 83,07 ppm of NOx, then -5º yaw angle is chosen.

1 INTRODUCTION

Coal is one of the most used energy sources, especially in power plants, according to data obtained from PT Bukit Asam (Indonesian mining company) at least 27 percent of the total energy produced in the world. While coal-fired power plants produce more than 39 percent of all electricity created in the world, this is because coal has a relatively easy and inexpensive extraction process, and infrastructure requirements are cheaper than other energy resources (BUMN, 2017). Based on the latest data obtained from the Geological Agency of the Ministry of Energy and Mineral Resources (ESDM), Indonesia's coal reserves amounted to 26.2 billion tons. With coal production of 461 million in 2017, the remaining coal reserves are 56 years old if there are no new reserves found (KESDM, 2016).

The level of coal consumption should reduce, so further research and innovation are needed. Much research has been done to reduce the level of coal consumption by increasing the efficiency of the boiler. One widely used boiler is a tangentially-fired boiler because it has the advantage of better combustion and can be used for broader classes of coal (Y.C. Liu et al., 2016). Although tangentially fired boilers have better combustion, there are still some problems such as carbon that does not burn in ash, unbalanced heat and there is a temperature deviation in the super-heater and reheater, numerical simulations can be successfully used to assess coal combustion and can observe the behavior of exhaust emissions from boilers on a large scale (Ho Young Park et al., 2012).

In coal-production, Indonesia is one of the coal-producing countries, with the majority of the quality of coal produced is medium calorie coal, whereas there are still many old plants that still use low-calorie coal. Under certain conditions, low-calorie coal supply cannot meet the needs of the generator, so that low-calorie coal will be mixed with medium quality coal, which is more widely available in other generating units (MEMR, 2016). In a numerical simulation study, it was shown that tangentially fired boilers with coal composition of 70% low-calorie coal with 30% medium calorie coal showed that there was a high-temperature build-up at the bottom of the boiler (Sa'adiyah et al., 2017).

To reduce the occurrence of gas temperature deviations in the boiler can be done by changing the yaw angle of over-fire water. This is indicated by the numerical simulation results, which show that

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changing the yaw angle of Secondary Over-Fire Water (SOFA) is a sufficient way to reduce gas temperature deviation. Numerical simulations show that changing the angle of SOFA and Closed Couple Over-Fire Water (CCOFA) can affect gas temperature and flow in the area around the superheater and reheater (Ho Young Park et al., 2015). Horizontal exhaust gas deviation decreases by changing the yaw angle from SOFA to negative direction, with Concentric Firing Secondary (CFS) water at an angle of 22º (Y.C. Liu et al., 2016). To reduce the occurrence of temperature deviation, it necessary to optimize airflow in the opposite direction from the secondary air (Ho Young Park et al., 2012). So based on this research, it is necessary to study the effect of the yaw burner angle which is expected to be able to overcome the temperature deviation at the bottom of the boiler which can determine the quality of coal combustion in the boiler which can affect the exhaust emissions produced, and also overcome future conditions if Indonesia lacks low coal calories. So from that, a numerical simulation study of the combustion characteristics of tangentially fired boilers with yaw angle variations was carried out.

2 NUMERICAL METHOD

The numerical simulation in this study using Computational Fluid Dynamics, which started with geometry build and meshes formation before setting the solving method. The geometry of the tangentially-fired boiler that will be used in this study is shown in Fig. 1(a). The furnace section will have 7 (seven) elevation, namely A, B, C, D, E, F, and G, with 1 (burner) at each corner of the elevation, or it can be said for each elevation there would be 4 (four) burner. Furthermore, this boiler also included CCOFA (Closed-coupled Over-Fire Air) near elevation G and SOFA (Separated Over-Fire Air) on the higher elevation.

The formation of boiler meshing is depicted in Figure 1 (b), which are using hexahedral at the rectangular shape and polyhedral at the non-rectangular shape to minimize the error due to unbalanced mesh size ratio. Meshing is a process of breaking domains into smaller volumes/forms that can facilitate stream domain discretization and can apply control equations to the flow domain. The domain of the coal burner is mass flow inlet, while CCOFA, SOFA, primary air, and secondary air are velocity inlet. The water wall-tubes on wall furnace are modeled as a heat sink that absorbs heat from flue gas (heat flux). All heat exchangers, from superheater to economizer, are modeled as a porous medium that also absorbs heat (heat generation). The last, the outlet will be modeled as a pressure outlet.

In this study 70% LRC type coal will be injected through the elevation of B, D, E, G burners and MRC type coal with a composition of 30% will be injected through elevations A and C, as suggested in Sa'adiyah et al. research, while at elevation F is in stand by position (deactivated).

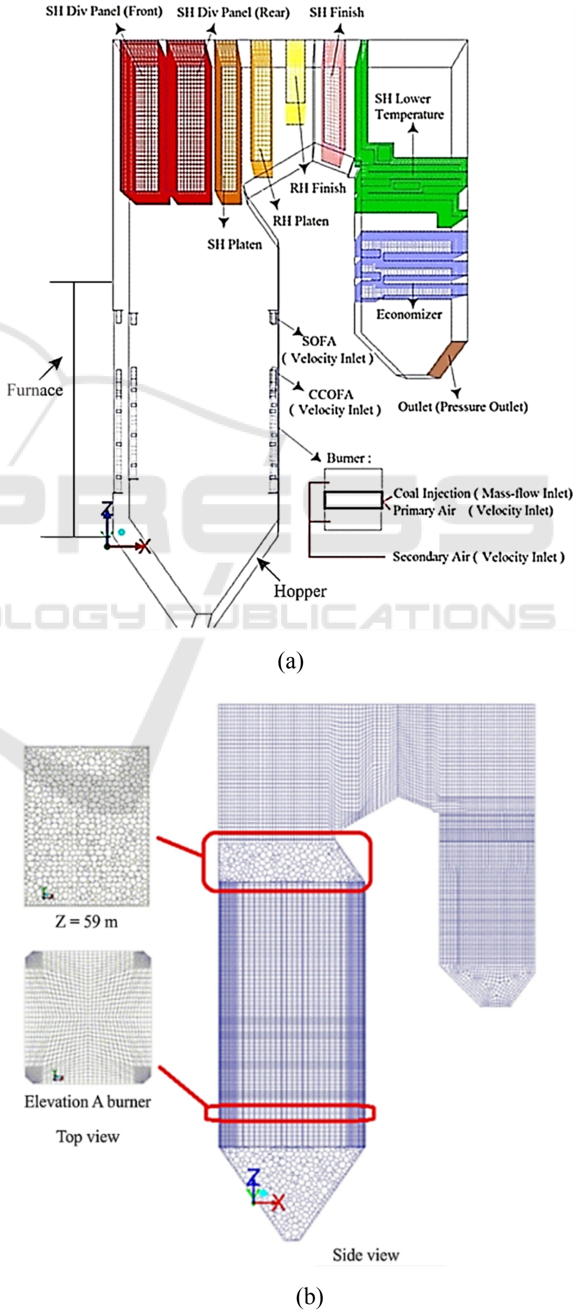


Figure 1: (a) Boiler geometry and (b) boiler mesh.

The original angle configuration for each coal injection and auxiliary air can be seen in figure 2 and Table 1. The change of yaw angle in this study is focused on secondary air injection angle, which will vary from + 5º, 0º, -5º, -10º, and -15º. The specific condition of coal injection and auxiliary air, including CCOFA and SOFA, are presented in Table 1.

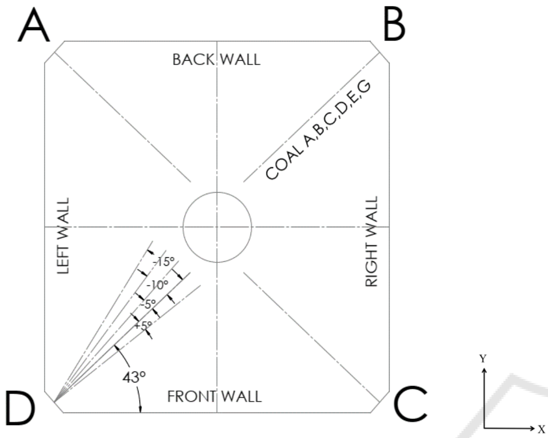


Figure 2: Yaw angle configuration.

Table 1: Auxiliary Air Boundary Condition.

Auxiliary Air	Angle (º)	Temperature (º C)	Velocity (m/s)
AA	0	359	59,749
A	0	66	22,8
AB	4.5	359	59,749
B	0	66	22,8
BC1	4.5	359	59,749
BC2	15	359	59,749
C	0	66	22,8
CD1	15	359	59,749
CD2	4.5	359	59,749
CD3	15	359	59,749
D	0	66	22,8
DE1	15	359	59,749
DE2	4.5	359	59,749
E	0	66	22,8
EF	4.5	359	Not activated (assumed as a wall)
F	0	66	
FG1	-20	359	
FG2 (LDO)	4.5	359	
FG3	-20	359	
G	0	66	22,8
GG	-25	359	59,749
CCOFA 1 & 2	-25	359	15,438
SOFA 1 & 2	0	359	11,8197

The solution used in this study is using the SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) algorithm, where least squares are cell-based for gradients, standard for pressure, first-order upwind for turbulent kinetic energy and turbulent dissipation rate, and second-order upwind for momentum, lig-vol, O_2, CO_2, H_2O, H_2, and CO. The use of these solutions is based on research by Chungen et al. (2003) and Choi and Kim (2009). The viscous model to simulates the turbulence flow inside the boiler is the standard k-ε model, while the coal combustion process using the species transport model.

3 RESULTS AND DISCUSSION

In the numerical simulation, before it can be continued to do further research, it should be relevant to the original condition called validation. The simulation results with the original condition have to be in the same line with minimal error. However, because the actual measured results only have CO_2 and O_2 emission percentages, then in this study, Table 2 points out the difference value O_2 and CO_2 concentration at the outlet in both actual and simulation data/ Computational Fluid Dynamic (CFD).

Table 2: Auxiliary Air Boundary Condition.

Emission at boiler exit	Plant Data (%)	CFD (%)	Error
O2	5,4	5,9	9%
CO2	14,8	15,5	4,7%

Table 2 shows that there is a reasonably small error in CO2 exhaust emissions which is below 5%, whereas in O2 exhaust emissions there is a difference of 9%, the simulation results show that the exhaust emissions data obtained at the outlet is entirely consistent with the actual data because the error is still below 10%, this refers to previous research where errors that occur in exhaust emissions between actual and simulated data have an error of 16% (Ho Young Park et al., 2012) and an error of 11% (Tan et al., 2017) So that this simulation can be used for further research.

3.1 Temperature and Velocity Distribution

The temperature distribution at the y-center cross-section is shown in Figure 3. The original case with default yaw angle 0˚ is depicted in Figure 3 (a). Based on the default configuration, the fire-ball swirling to clockwise direction. The injection of MRC to burners at elevation A and C makes high-temperature distribution above the hopper zone because MRC has a high heating value. Then the heat from MRC combustion accelerates the burning rate of LRC at the other burner elevation. The high temperature increases the devolatilization process, so the char of LRC burned faster. Therefore the combustion process complete right before entering the superheater and reheater area. However, the temperature before entering the superheater area is still relatively high that needs to be considered to prevent the damage of the superheater tube from overheated.

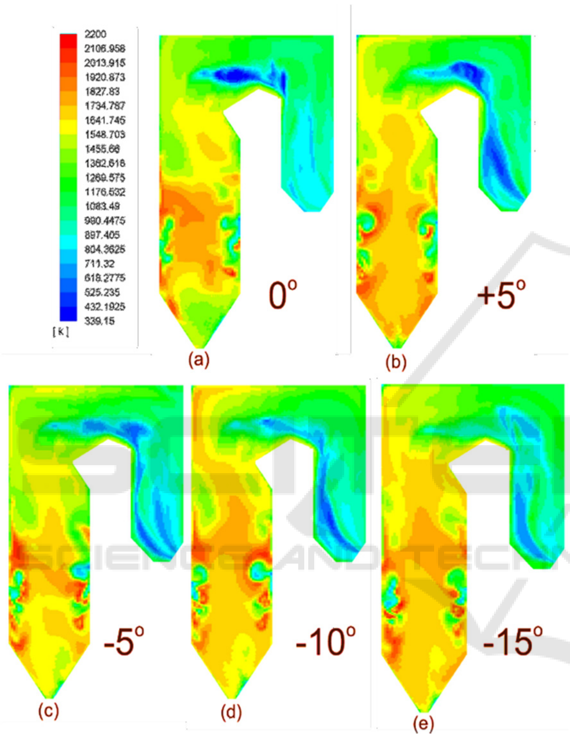


Figure 3: Temperature distribution at the y-center cross-section.

The first case which uses +5˚ yaw angle has the opposite direction of fire-ball, this condition weakens the fire-ball. Rather than moving upward, the fire-ball tends to move to the hopper zone. The combustion process then also takes place in the hopper zone; that is why the red color shown in Figure 3 (b). However, because almost all MRC get burned at hopper zone and at a lower elevation, the LRC at higher elevation did not get enough heat to speed up the burning time, then the uncomplete combustion of LRC moving upward to superheater area and get burned in that area.

The observation of temperature distribution with yaw angle -5˚, -10˚, and -15˚ showed in Figure 3 (c-e). For these cases, the yaw angle sprays air in the same direction with fire-ball rotation. The increasing of yaw angle makes the fire-ball become wider to the vicinity of wall-burner also decrease the turbulence. The wider fire-ball expands the combustion area and let the coal get complete combustion before entering the next elevation and the superheater area. However, for numerical simulation with -10˚ shows, the combustion process delayed until the superheater area and got worse when using -15˚. This can happen because after increasing the yaw angle, the air injection also directing some coal to the wall-furnace and get burned. The red color occurs in the vicinity of the burner, which indicated a very high temperature. While the combustion takes place near the wall furnace, the intake of air becomes insufficient at the center, causing uncomplete combustion, the flow with uncomplete combustion coal moving upward, and get burned at the superheater area and damage superheater tubes.

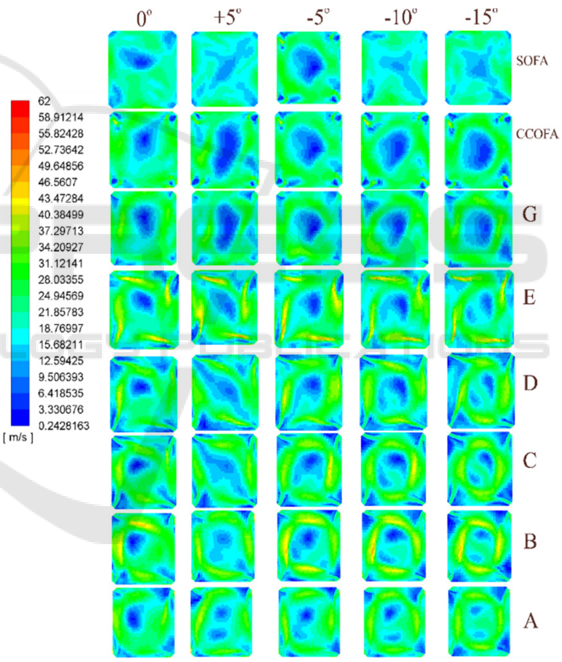


Figure 4: Velocity distribution at each elevation.

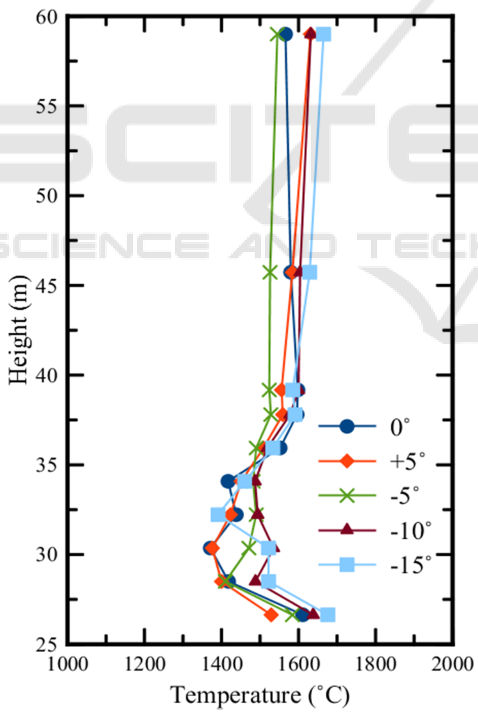
The phenomena that happened in the distribution of temperature at each elevation strengthened with the distribution of velocity, as shown in Figure 4. Simulation with +5° yaw angle made the velocity distribution spread and dispersed the fire ballet elevation C & D. While on the negative yaw angle, the velocity distributes evenly from bottom elevation, elevation A, until SOFA elevation, especially with the case -5° yaw angle.

Table 3: Height for each elevation.

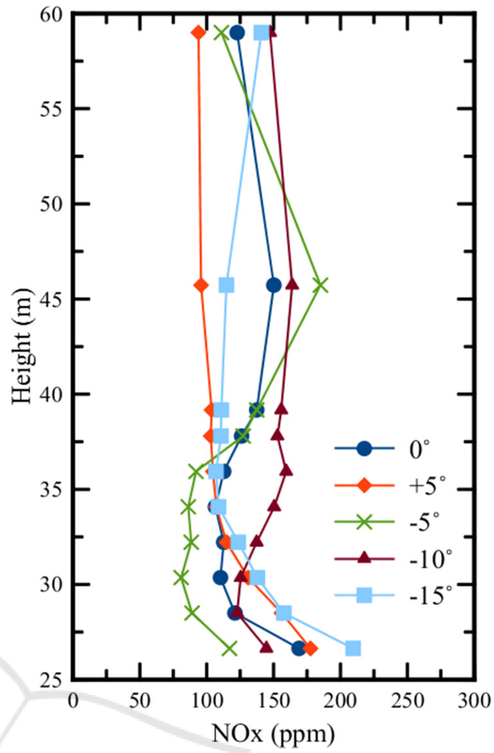
Elevation	Height (m)
A	26.64
B	28.5
C	30.36
D	32.22
E	34.08
F	35.94
G	37.8
CCOFA	39.17
SOFA	45.73

3.2 NOx Emission

The special condition of this study is the mixed fuel that has been used, namely MRC and LRC, which need modification of yaw angle to reduce the consumption of coal. Furthermore, the emission also needs to be considered, called NOx, to offer the best yaw angle. Figure 5 depicted the average temperature and NOx concentration. The height shown in the graph is the height of each elevation, Table 3.



(a)



(b)

Figure 5: Velocity distribution at each elevation.

The higher temperature will have higher NOx concentration. However, the average value for both temperature and NOx concentration can not represent the actual phenomena inside the boiler; the further observation of NOx is need inside the boiler, Figure 6.

The NOx production relies on temperature and the amount of nitrogen and oxygen in the flue gas. When the temperature is higher than 1800K (El-Mahallawy, 2002), the nitrogen from air and coal will react with oxygen to generate NOx emission. The original case with 0˚ produced high enough NOx species in the furnace area, Figure 6 (a). The NOx generation also occurs until the outlet of the boiler, although only with a small amount. This indicates still there is enough heat, nitrogen, and oxygen to produce more NOx.

The combustion with yaw angle +5˚, as shown in Figure 6 (b), generated a high amount of NOx in the hopper zone until the middle of the furnace area, and this is happening because of the very high temperature formed due to MRC combustion. Despite high NOx production at the lower part of the furnace, the other area includes the heat exchanger area forming the only little amount of NOx since all combustion processes, which produce high heat ends at the furnace zone.

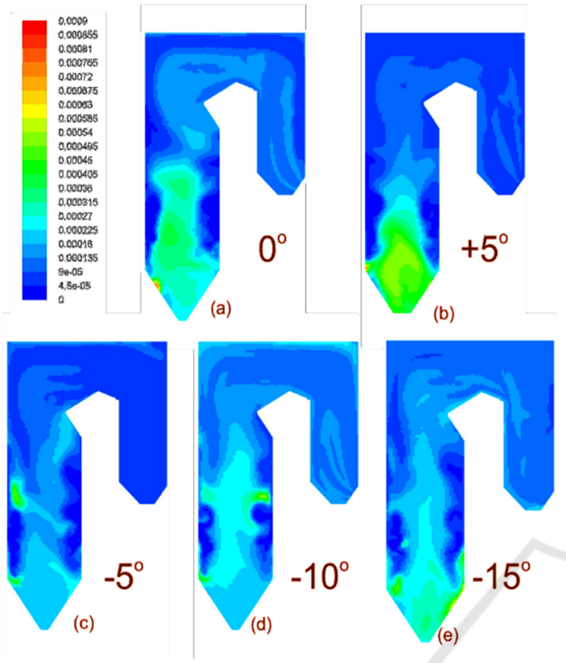


Figure 6: NOx distribution at the y-center cross-section.

The distribution of NOx with -5˚, -10˚, and -15˚, which conceived in Figure 6 (c-e), shows that NOx generation increased as the increasing of yaw angle. The highest NOx formed at the lower part of the furnace of -15˚ yaw angle simulation. Regardless of the highest NOx amount at -15˚ yaw angle, represented by green color, the simulation with -10˚ yaw angle actually generates more NOx. As can be seen in Figure 6 (d), NOx formation also happens in the upper part of the furnace and on the heat exchanger area. While comparing to all cases with negative yaw angle, the case with +5° yaw angle produce a relatively small amount of NOx than others.

Table 4: NOx emission at boiler exit

Yaw angle	NOx (ppm)
0º	113,32
+5º	87,62
-5º	83,07
-10º	145,04
-15º	126,43

Observation of flue gas emission is also taken place at the boiler exit to know how the yaw angle variation affected the emission results before going out to the atmosphere. Table 4 discloses the amount of each emission for each variation of the yaw angle. It shows the variation of the yaw angle really affects the emission, with less emission is provided in -5° yaw angle case.

4 CONCLUSION

In this study, Computational Fluid Dynamic modelings were developed to investigate the effect of the burner yaw angle on the combustion characteristic and gas emission of a 625 MWe tangentially fired boiler with mixed coal (70% LRC & 30 % MRC). The Computational Fluid Dynamic model was validated against measured results were found to be both qualitatively and quantitatively consistent. As the burner yaw angle going wider, the temperature deviation also higher, which happened on the upper furnace. The coal burner yaw angle that has the best temperature distribution is at -5º because it has the least temperature deviation on the upper furnace, which minimizes the risk of overheat on superheaters and reheaters. The least NOx is happened at -5º yaw angle, with the result is 83,07 ppm because of the NOx production process at the furnace effect the results of NOx at the boiler outlet.

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