Analysis of Combustion Characteristic in Tangentially Fired Pulverized-Coal Boiler with Tilting Burner Angle Variation using CFD

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Abstract. One type of boiler is a boiler with tangential combustion. Tangential combustion is combusted with a burner arrangement located at each corner (corner) of the boiler, where each burner forms a certain angle to the boiler wall. Most of the tangential boilers are equipped with a tilting burner facility. An inclined burner is a facility to direct the burner to face up or down a certain angle to a horizontal line. Changes in the direction of the burner tilt angle will move to the fireball position in the furnace so that there can be changes in temperature, velocity, also species. This study was conducted to determine setting the burner tilt angle by varying the angle simulated using CFD. The data to be obtained are qualitative data in the form of contours and vectors from the distribution of temperature and velocity and quantitative data in graphs and tables. In this study, it is hoped that the ideal angle for the boiler will be obtained so that combustion in the boiler occurs efficiently.

1. Introduction

Power plants play a crucial role in the need for electrical energy. Research and innovations in the field of power plants significantly impact the advancement of electrical technology. Trisnayanti et al. [1] and Satrio et al. [2] researched the fuel side, where the research aimed to determine the effect of fuel replacement on performance and fuel consumption in a steam power plant. Kurniawati et al. [3] researched one of the main components in the power plant, the condenser. This research aims to determine the performance of the condenser and the efficiency of the power plant cycle, which is influenced by the temperature and flow rate of the cooling water.

Tangential combustion boilers are the most widely used boiler types for coal combustion in industry. It is because tangential combustion has several advantages, such as good ignition distribution and even heat flux to the furnace wall, reducing the thermal stress on the water wall tube in the boiler. Also, tangential combustion can produce maximum combustion, reducing carbon emissions and reducing coal waste that does not burn.

In a tangential boiler, several corners have burners, where each burner forms a certain angle to the boiler wall. The burner on this boiler can be angled up and down. This facility is more commonly called a tilting burner. The tilting of the burner on the burner can be changed to adjust the temperature of the reheated steam outlet. The tilting burner setting can affect the coal combustion process in the boiler [4].
Some examples of problems in boilers are combustion instability at low load, heat imbalance and gas temperature deviation in the superheater & reheater, and slagging in the furnace [5]. In the case of a furnace boiler, there is often an uneven temperature distribution. The impact of the uneven temperature distribution is that imperfect combustion can occur in the boiler furnace, thus making the efficiency of the boiler decrease. So, the steam temperature needs to be increased. Increasing the steam temperature in the burner can be done by tilting the angle during actual operation [5]. Manipulation of the burner tilt angle is an operational methodology in controlling temperature [6]. However, the temperature of the steam in the reheater can rise, which will cause overheating if the tilt angle is too high. Therefore, the angle of inclination of the burner must be adjusted and determined in order to meet various criteria [7].

The literature study was conducted from previous research on tangential boilers. Fanny Eka [8] researched the characteristics of combustion by varying the injection of oxy-fuel in the combustion air. Meanwhile, Rina [9] examined the characteristics of combustion using oxy-fuel in the case of coal blending MRC and LRC. Also, Chen’s [10] research examines Numerical investigations on different tangential arrangements of burners for a 600 MW utility boiler.

Based on the studies that have been carried out, the results of varying the value of the tilting angle are as the burner tilts angle increases, the temperature distribution in the furnace changes significantly, and the high-temperature area shifts towards the middle and the top of the furnace [7]. When tilting is directed upwards, the flow coming out of the burner will push the previous flow out so that the flow is directed towards the centre of the boiler [4].

In this research, an analytical study of the effect of tilting angle variations on the combustion characteristics of a tangentially fired pulverized-coal boiler was conducted using Computational Fluid Dynamic (CFD). This study will discuss the temperature distribution and velocity distribution in the furnace.

2. CFD Simulation
There are some steps that have to be completed in computational fluid dynamic simulation. The explanation of each step will be explained as follows.

2.1 Pre-processing

2.1.1. Geometry

![Furnace geometry](image)

**Figure 1.** Furnace geometry.

In this study, to simplify the simulation, the geometry used is 2D. The observed object is limited to the boiler furnace only. Figure 1a is a representation of the tilting burner angle being upward by +15º. Figure 1b is a representation of the default tilting burner. Moreover, Figure 1c is a representation of the tilting burner angle being downward by -15º.
Table 1. Furnace dimension.

| Surface          | Value | Units |
|------------------|-------|-------|
| Furnace Height   | 23.867| m     |
| Furnace Width    | 97.155| m     |
| Burner Height    | 00.24 | m     |
| Burner Width     | 00.45 | m     |
| Tilting Burner Angle Variation | +15°  | -     |
|                  |       | -15°  | -     |

2.1.2. Meshing

The meshing process enumerates the domains into smaller numbers. In the meshing process, it is necessary to adjust the size of the geometry. Then determine the section and the type of meshing.

2.1.3. Boundary Condition

Determination of boundary conditions is used to define functions on the geometry that has been created. The inlet used in this research is "mass flow inlet". Furthermore, the outlet is defined as a "pressure outlet". Then another part is defined as a "wall". In this study, 12 burners are described 4 burners as primary air and 8 burners as secondary air. Primary air itself functions as fuel injection into the furnace. By reference, burner E is not being operated. The order of the burner arrangement can be shown in the Figure 3.
An illustration of this condition can be seen in the Figure 4.

**Table 2. Boundary conditions**

| Named               | Description             |
|---------------------|-------------------------|
| **Inlet**           |                         |
| Inlet Type          | Mass flow inlet         |
| Burner Type         | Primary air             |
| Mass Flow Rate      | Secondary air           |
| Secondary Air       | 6.68 kg/s               |
| Primary Air         | 3.5 kg/s                |
| **Outlet**          |                         |
| Outlet Type         | Pressure                |
| Temperature         | 1,094 K                 |
| Pressure            | 453.4 Pa                |
2.2 Processing

The simulation setup for this paper uses the finite volume method. The algorithm is SIMPLE. The Standard K-ω uses as a viscous turbulence model. The governing equations such as continuity, momentum, and energy equations are discretized by the first-order upwind numerical scheme—pressure discretized by the standard. The solutions converge when the residual continuity values are $10^{-5}$ for all variables and $10^{-6}$ for the energy equation.

3. Results and Discussion

3.1 Validation

Before data collection and analysis, the data validate first. Validation is done by comparing the simulation value with the reference value. Validation carries out on the pressure value located at the outlet area of the burner, which was -85.53 Pa. The results obtained from the simulation are -84.41 Pa.

3.2 Grid Independence

Before making variations on the simulation, the grid independence should check first. In this study, a grid applies to reduce the mesh size and increase the accuracy. The grid independence test carries out in 5 meshing models with variations in the number of elements: a) 25796, b) 31867, c) 39404, d) 52361, e) 69166.

| Variation | Element | Pressure Simulation | Pressure Actual | Error (%) |
|-----------|---------|---------------------|----------------|-----------|
| a         | 25,796  | -8,772              | -8,553         | 25        |
| b         | 31,867  | -8,312              | -8,553         | 228       |
| c         | 39,404  | -8,441              | -8,553         | 13        |
| d         | 52,361  | -8,475              | -8,553         | 9         |
| e         | 69,166  | -8,688              | -8,553         | 15        |

3.3 Temperature Distribution

The purpose of combustion in the power plant combustion chamber is to convert the chemical energy contained in the fuel into heat to change the working fluid phase. Combustion efficiency is often related to the temperature in the combustion chamber. Observations were also made at each burner injection elevation. The temperature contour can be seen in Figure 5. Contour making uses a plane with a colour map range of 100 K – 2800 K. The highest temperature occurs in the furnace because it is a place of combustion.

On the contour of the temperature distribution, it can see that the high temperature is in the centre of the furnace, where combustion occurs in that area. The temperature around the wall in the three variations tends to be low because the temperature distribution only occurs in the middle of the furnace. The temperature distribution in the three variations has the same tendency.

At an angle of +15°, the flames resulting from combustion tend to move upward so that the combustion does not touch the bottom ash hopper. It can see that the bottom ash hopper area has a low temperature. At this +15° angle setting, it produces an average outlet temperature of 2392.62 K.

At an angle of 0°, the shape of the flame resulting from combustion is in the centre of the furnace. It is because the tilting angle of the burner is at its standard condition. Although the combustion does not reach the bottom ash hopper area, it can seem that the temperature in that area is higher than the +15° angle setting. At the 0° angle setting, the average outlet temperature is 2305.33 K, 87.29 K lower than the +15° angle setting.

At an angle of -15°, the shape of the flames resulting from combustion forms a temperature distribution that is not too wide compared to the previous 2 angles. It is due to the angle that leads down so that the temperature distribution is less able to spread in the section near the furnace outlet. The average outlet temperature resulting from the -15° angle setting is 2325.98 K. Which is higher than the 0° angle setting.
3.4. Velocity Distribution
Take the velocity contour on the furnace to determine the distribution of the flue gas flow. The results of the velocity magnitude contour data show in the following figures.

In Figure 7, it can see that in the three variations of the angle, there is a tendency for the flue gas velocity to increase as it goes to the furnace outlet. The combustion that occurs in the middle of the furnace causes turbulence in the area, which is then from the middle of the furnace to the outlet with a smaller cross-sectional area, so turbulence occurs in the area approaching the furnace outlet. It can see from the legend area near the furnace outlet, which is red, which indicates the flue gas velocity in that area is higher than in other areas.

Then in the bottom ash hopper area, the flue gas flow tends to be lower than in other areas. It is because the combustion does not reach the bottom ash hopper area.
3.5. O2 Distribution

One method to analyze combustion is to analyze the mass fraction of O2. Complete combustion is characterized by the least amount of mass fraction O2. The value of O2 is taken quantitatively by taking the average value of O2 in the furnace. The distribution contour of O2 can be seen in the following figures.

Complete combustion is when O2 is wholly absorbed or does not produce O2. The three variations show that the middle area of the furnace, indicating that oxygen is almost entirely consumed to oxidize coal particles in the combustion process, is marked with a dark blue legend.

Then in the area around the wall, there is still oxygen. It is because there is no burning in the area. It can also be due to excess air, so oxygen is not absorbed completely.

3.6. CO2 Distribution

Another method to analyze combustion is to analyze the CO2 mass fraction. CO2 is a product of combustion. Observations on CO2 indicate the success or failure of combustion.

CO2 contour. Identical to the temperature contour, where a high CO2 mass fraction indicates complete combustion. In the three angle variations, the highest CO2 is in the area in the middle of the furnace, where combustion occurs. However, the angle setting that produces better CO2 is at an angle of +15°, which it can see in the orange to red legend, which shows that the CO2 value is higher at the +15° angle setting compared to other angles.
4. Conclusion
Based on the research which has been done, the following conclusions are:

1. Modification in the tilting angle of the burner can affect changes in the furnace's outlet temperature. When the tilting angle of the burner is directed upwards by 15°, the resulting temperature is higher than when the tilting angle of the burner is 0° and -15°.
2. The three varied angle settings both produce a flow that tends to be high in the centre area of the furnace to the outlet of the furnace. It is due to the occurrence of turbulence caused by combustion in the furnace.
3. Changes in the tilting angle of the burner affect the combustion results in the furnace. Burning at an angle of +15° is more suitable than at 0° and -15°. It proves that the CO2 produced by the +15° angle setting is higher than the other.
4. The three varied angle settings both resulted in a low O2 content in the middle area of the boiler. It indicates that oxygen is wholly absorbed in the centre area of the furnace.
5. The +15° angle setting results in better combustion because it produces a higher outlet temperature, also produces higher CO2 compared to 0° and -15° angles.

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