CFD Modeling to Analyze Palm Shell Co-firing Percentage on Ketapang CFB Power Plant

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Abstract. Biomass is one of the world's greatest sustainable energy potentials. Utilization of biomass in the form of Co-firing coal fuel with biomass is one alternative to reduce the dependence of fossil fuels towards green power plant. This paper addresses Co-Firing modelling test results up to 50% biomass using palm kernel shell (palm kernel shell) in Ketapang Coal Fired Power Plant (CFPP) 2x10 MW. Ketapang CFPP has circulating fluidized bed (CFB) boiler. There are several advantages by using direct co-firing in CFB boiler: direct co-firing has the lowest investment cost, CFB has a wider range of biomass selection characteristics and characteristics than PC Boilers, CFB can process biomass materials with higher moisture content, etc. Result shown that the optimum percentage of palm kernel shell biomass use in the Ketapang Power Plant is 30% palm kernel shell. This is caused by the temperature value at 18 cm above the furnace bed and furnace exit gas temperature of 30% palm kernel shell which is not too much different from the temperature value at 18 cm above the bed furnace and furnace exit gas temperature of 0% palm kernel shell. This is also strengthened by the high value of the CO₂ mass fraction in the 30% palm kernel shell mixture, which indicates that an ideal combustion.

1. Introduction
Recently, the world is experiencing global climate change which impacts on global disasters. The United Nations Framework Convention on Climate Change (UNFCCC) states that Indonesia is committed to contribute in global climate change solutions. Various solutions are given to tackle this changing global climate issue. One solution is to reduce greenhouse gas (GHG) emissions. Greenhouse gases (GHGs), which are the cause of global warming, are derived from emissions from the burning of fossil fuels (petroleum and coal) as well as from deforestation and forest burning [1]. The Paris Agreement states that the reduction of Greenhouse Gas (GHG) emissions by 29% against Business As Usual (BAU) in 2030.

In connection with that, the government will also continue to encourage the development of a number of renewable energy-based power generation (EBT) projects such as hydro power plant (HPP) and biomass power plant. The National Energy Mix notes that the contribution of EBT has only reached 12.52%. At present, the use of renewable energy is still relatively low at around (1.9%) 8,215.5 MW. Meanwhile, the potential of EBT into energy can range around 443,208 MW. One source of EBT in Indonesia that can be utilized is biomass. Biomass is a material derived from living organisms which includes plants, animals and by-products such as garden waste, harvest products and so on. Biomass can play an important role as a renewable energy source, which functions as a provider
of carbon sources for energy [2]. Potential biomass in biomass power plant is by using Palm Kernel Shell (palm kernel shell). Palm kernel shell is also used as fuel in biomass power plant in several countries, where foreign countries have imported from Indonesia. The production of these palm kernel shells in Indonesia reaches 9.2 million tons a year. But at the moment, there is an increase in taxes in the export of palm kernel shell, and therefore it is necessary to increase the use of this palm kernel shell in the country. Ketapang Power Plant has implemented and increased the utilization of the use of this palm kernel shell biomass. [3]

2. Material and Method

2.1 Preparation of palm kernel shell and Temporary Biomass Storage
Co-firing test conducted on Ketapang CFPP unit #2 with palm kernel shell share of 3% and 5%. Total coal flow 11 ton/hour for 10 MW load with 8 hours test for each test, and palm kernel shell supply needed for the test is 12 ton until 5% palm kernel shell.

2.2 Co-firing Test Methods
Direct co-firing was used in this experiment. Palm kernel shell and coal blended at the coal yard. Biomass handling done by existing heavy equipment near the emergency reclaim hopper/underground hopper. Mixing process (see Fig. 4) between coal and palm kernel shell done in coal yard with excavator. Coal-palm kernel shell mixing go inside coal bunker through underground hopper with percentage as planned (3% and 5%). Co-firing was done in the furnace. The test took 8 hours; 2 hours for stabilizing the mixture in combustion and 6 hours for data collecting. [4]

2.3 Palm Kernel Shell as Biomass
Palm kernel shell is the shell that remains after the fat has been removed and has been destroyed in the palm oil mill [5]. Kernel skin is a fibrous material, brownish yellow in color and with particle sizes typically ranging between 5 mm and 40 mm [6]. Comparison between coal and palm kernel shell shown on Table 1. Palm kernel shell low total sulfur compared to coal can reduce sulfur-related emission. High volatile matter on palm kernel shell can helps faster combustion in boiler, led to lower FEGT. Low ash palm kernel shell can reduce ash formed (fly ash and bottom ash).

Table 1. Comparison between coal and palm kernel shell. [7,8]

| Parameter          | Unit (Ar) | Coal A | Coal B | palm kernel shell |
|--------------------|-----------|--------|--------|-------------------|
| **Ultimate**       |           |        |        |                   |
| Carbon             | %         | 48,61  | 43,82  | 47,62             |
| Hydrogen           | %         | 3.75   | 3.37   | 5.14              |
| Nitrogen           | %         | 1.09   | 0.68   | 0.26              |
| Sulphur            | %         | 0.63   | 0.11   | 0.05              |
| Oxygen             | %         | 13.95  | 13.22  | 35.87             |
| **Proximate**      |           |        |        |                   |
| Total Moisture     | %         | 24.32  | 35.84  | 9.91              |
| Ash Content        | %         | 7.66   | 2.96   | 1.16              |
| Volatile           | %         | 34.43  | 30.97  | 70.37             |
| Matter             |           |        |        |                   |
| Fixed Carbon       | %         | 33.59  | 30.24  | 18.56             |
| Total Sulphur      | %         | 0.63   | 0.05   |                   |
| GCV                | kCal/kg   | 4897   | 4145   | 4543              |
| HGI                |           | 47     | 55     | <32               |
| Bulk Density       | kg/m³     | 900    | 890    | 409               |
3. Result and Analysis

3.1 Baseline and 5% Co-Firing Parameter Observation
100% coal performance test and 5% co-firing test using coal with calorific value 4,145 kcal/kg. Monitoring done on load setting 10 MW. Critical parameter is monitored while testing. The data shown a normal FEGT value (<950°C), normal bed temperature (between safe limits of boiler design manual 790-910°C), as well as normal air chamber pressure. [9]

3.2 Ketapang Power Plant Co-firing Modeling and Simulation
For the modeling and simulation, a biomass co-firing simulation is done by 0% biomass mixing. Simulation is done by mixing biomass and coal through the same coal inlet using Ansys Software 19.0 [10]. The temperature contours on the furnace bed for 0% and 5% palm kernel shell can be seen in the following Figure 1 and Figure 2.

![Figure 1](image1.png)
Figure 1. Temperature contour of 0% palm kernel shell in furnace bed plane XZ with height (a) position at 18 cm, (b) position at 1 m, (c) position at 5 m, and (d) position at 12 m

![Figure 2](image2.png)
Figure 2. Temperature contour of 5% palm kernel shell in furnace bed plane XZ with height (a) position at 18 cm, (b) position at 1 m, (c) position at 5 m, and (d) position at 12 m

The temperature contour at the furnace exit gas temperature for 0% and 5% palm kernel shell can be seen in Figure 3 below.
Based on the temperature contour above, an average value of 18 cm above the furnace bed and furnace exit gas temperature is taken. Data on the comparison value of simulation temperature results with experiments can be seen in Table 2 below.

Table 2. Temperature comparison of simulation results with experiments in the Ketapang Power Plant.

| PKS Percentage (%) | Temperature at 18 cm above the furnace bed | Error (%) | Temperature of FEGT | Error (%) |
|-------------------|------------------------------------------|-----------|---------------------|-----------|
|                   | Experiment | Present Study |                   | Experiment | Present Study | |
| 0                 | 902 | 856 | 5.09 | 850 | 895 | 5.29 |
| 5                 | 896 | 826 | 7.81 | 844 | 817 | 3.19 |

In this study, the percentage of biomass was varied from 5% to 50% with an interval of 5%. Several physical contours such as temperature, velocity, mass fraction of CO$_2$, and wall shear stress will be presented.

3.2.1 Temperature Distribution

The contour of the temperature distribution data on a mixture of 0% to 50% palm kernel shell is done at a height of 18 cm above the furnace bed, vertical plane in the middle of the furnace and at FEGT. The temperature contour at a height of 18 cm above the furnace bed can be seen in the following Figure 4.

Figure 4. Temperature contour at a height of 18 cm above the furnace bed plane XZ (a) 0%, (b) 5%, (c) 10%, (d) 15%, (e) 20%, (f) 25 %, (g) 30%, (h) 40%, and (i) 50% palm kernel shell.
The temperature contour in the middle vertical plane of the furnace can be seen in Figure 5 below.

**Figure 5.** Temperature contour at middle vertical field furnace plane XY (a) 0%, (b) 5%, (c) 10%, (d) 15%, (e) 20%, (f) 25 %, (g) 30%, (h) 40%, and (i) 50% palm kernel shell

The temperature contour at furnace exit gas temperature can be seen in Figure 6 below.

**Figure 6.** Temperature contour at furnace exit gas temperature bed plane YZ (a) 0%, (b) 5%, (c) 10%, (d) 15%, (e) 20%, (f) 25 %, (g) 30%, (h) 40%, and (i) 50% palm kernel shell

3.2.2 CO₂ Distribution
The CO₂ distribution contour in a variation of a mixture of 0% to 50% palm kernel shell is done in the vertical plane in the middle of the furnace and at FEGT. The CO₂ distribution contour in the vertical plane in the center of the furnace can be seen in Figure 7 below.
Figure 7. CO$_2$ distribution contour at middle vertical field furnace plane XY (a) 0%, (b) 5%, (c) 10%, (d) 15%, (e) 20%, (f) 25%, (g) 30%, (h) 40%, and (i) 50% palm kernel shell

The CO$_2$ distribution contour at furnace exit gas temperature can be seen in Figure 8 below.

Figure 8. CO$_2$ distribution contour at furnace exit gas temperature plane YZ (a) 0%, (b) 5%, (c) 10%, (d) 15%, (e) 20%, (f) 25%, (g) 30%, (h) 40%, and (i) 50% palm kernel shell

3.2.3 Velocity Distribution

The velocity distribution contour in a variation of a mixture of 0% to 50% palm kernel shell is done at the height of 18 cm above the furnace bed, 11 m above the furnace bed and 19 m above the furnace bed. The velocity distribution contour of 0%, 30%, and 50% palm kernel shell can be seen in the following Figure 9, Figure 10, and Figure 11 below.

Figure 9. Velocity contour with 0% palm kernel shell at a height of (a) 18 cm above the furnace bed, (b) 11 m above the furnace bed and (c) 19 m above the furnace bed.
Figure 10. Velocity contour with 30% palm kernel shell at a height of (a) 18 cm above the furnace bed, (b) 11 m above the furnace bed and (c) 19 m above the furnace bed.

Figure 11. Velocity contour with 50% palm kernel shell at a height of (a) 18 cm above the furnace bed, (b) 11 m above the furnace bed and (c) 19 m above the furnace bed.

3.2.4 Shear Stress Distribution
The shear stress distribution contour was taken from 0% to 50% palm kernel shell variations made on the front side, left side, right side, and back side of the furnace [11]. Contour of shear stress distribution at 0%, 30%, and 50% palm kernel shell can be seen in the following Figure 12, Figure 13, and Figure 14 below.

Figure 12. Shear stress contour with 0% palm kernel shell percentage on (a) left side of furnace, (b) front side of furnace and (c) right side of furnace, and (d) back side of furnace.

Figure 13. Shear stress contour with 30% palm kernel shell percentage on (a) left side of furnace, (b) front side of furnace and (c) right side of furnace, and (d) back side of furnace.
Based on Figure 12 to Figure 14, several analysis results can be made, there are: (1) At 0% of biomass, maximum shear stress occurs in the cyclone area, as well as systems with 5% -35% biomass. This area of maximum shear stress becomes greater when biomass percentage increases. In other words, in the wall furnace area, the potential for erosion will not occur, (2) At 40 and 45% of biomass, the maximum shear stress shifts to the wall furnace area so that the potential for erosion, (3) To prevent erosion in the furnace, use a large percentage of biomass (> 35% biomass) is not recommended. This result is in accordance with velocity contour analysis.

3.3 Determination of Optimal Biomass

Based on the contours shown above, we can take the values of each contour of temperature and mass fraction of CO₂ for mixed variations with 0% to 50% palm kernel shell percentage. The simulation temperature values of the palm kernel shell mixture variations in the horizontal plane 18 cm above the furnace bed can be seen in Table 3 below.

### Table 3. Simulation temperature values of palm kernel shell mixture variations in the horizontal field position 18 cm above the furnace bed.

| Palm Kernel Shell Percentage (%) | Temperature Value at 18 cm Above the Furnace Bed |
|----------------------------------|--------------------------------------------------|
|                                  | Average  | Maximum |
| 0                                | 856      | 946     |
| 5                                | 826      | 1045    |
| 10                               | 825      | 1011    |
| 15                               | 861      | 956     |
| 20                               | 831      | 922     |
| 25                               | 801      | 1040    |
| 30                               | 857      | 933     |
| 35                               | 863      | 1025    |
| 40                               | 831      | 881     |
| 45                               | 825      | 834     |
| 50                               | 817      | 867     |

The simulation temperature values of the palm kernel shell mixture variations in the furnace exit gas temperature can be seen in Table 4 below.
Table 4. Simulation temperature values of palm kernel shell mixture variations in the furnace exit gas temperature.

| Palm Kernel Shell Percentage (%) | Temperature Value at FEGT | Average | Maximum |
|----------------------------------|---------------------------|---------|---------|
| 0                                | 895                       | 912     |         |
| 5                                | 817                       | 834     |         |
| 10                               | 805                       | 842     |         |
| 15                               | 852                       | 948     |         |
| 20                               | 828                       | 854     |         |
| 25                               | 790                       | 856     |         |
| 30                               | 837                       | 861     |         |
| 35                               | 820                       | 879     |         |
| 40                               | 812                       | 816     |         |
| 45                               | 798                       | 803     |         |
| 50                               | 791                       | 858     |         |

The simulation CO₂ mass fraction values of the palm kernel shell mixture variations in the furnace exit gas temperature can be seen in Table 5 below.

Table 5. Simulation CO₂ mass fraction values of palm kernel shell mixture variations in the furnace exit gas temperature.

| Palm Kernel Shell Percentage (%) | CO₂ Mass Fraction in FEGT | Average | Maximum |
|----------------------------------|---------------------------|---------|---------|
| 0                                | 0.125614                  | 0.143669|         |
| 5                                | 0.134943                  | 0.150446|         |
| 10                               | 0.131751                  | 0.138817|         |
| 15                               | 0.080683                  | 0.0946706|       |
| 20                               | 0.147643                  | 0.151224|         |
| 25                               | 0.092626                  | 0.09451 |         |
| 30                               | 0.142897                  | 0.164764|         |
| 35                               | 0.159395                  | 0.158737|         |
| 40                               | 0.154164                  | 0.1553  |         |
| 45                               | 0.057205                  | 0.062782|         |
| 50                               | 0.0648214                 | 0.080056|         |

4. Conclusion

From the research conducted on the co-firing of the Ketapang CFPP, several conclusions can be given as follows:

1. High temperatures above the furnace bed spread more evenly along the horizontal plane than the 0% biomass system. The maximum temperature which initially occupied a wider area along the middle area of the furnace (vertical plane), decreases with increasing% of biomass. The decrease in furnace temperature is caused by differences in the heating value of coal and palm kernel shells.

2. When biomass is added, the velocity profile does not change much in the Z axis direction when compared to the 0% biomass system. Only at 40 and 45% of biomass is there an indication of increased velocity in the area near the wall both horizontally and vertically which has the
potential to cause erosion. So the use of a large percentage of biomass, which is 40% and 45% is not recommended.

3. Based on the study conducted, it can be concluded that the optimum percentage of palm kernel shell biomass use in the Ketapang power plant is 30% palm kernel shell. This caused by the temperature value at 18 cm above the bed furnace and furnace exit gas temperature of 30% palm kernel shell which is not too much different from the temperature value at 18 cm above the bed furnace and furnace exit gas temperature of 0% palm kernel shell. The determination of the recommended percentage of this palm kernel shell mixture is also strengthened by the high value of the mass fraction of CO₂ in the 30% palm kernel shell mixture which indicates that combustion in the furnace occurs completely.

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