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Numerical Investigation of Biomass Cofiring Impacts on Flame Structure and Emissions

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ABSTRACT

Fossil fuels have been used widely for power generation. Emphasis should be given to the usage of renewable energy for power generation to reduce our dependence on primary fossil fuels. The burning of biomass with fossil fuels has a positive impact, both on the environment and the economics of power generation. Both coal and biomass are chosen because they have great potential to be developed in future for power generation in Malaysia. The aim of this study is to investigate the impacts of burning biomass with coal on the pollutant emissions and combustion performances of this cofiring. Type of biomass used is sawdust and simulation is done using CFD code FLUENT software. A good understanding of the combustion and pollutant generating processes in the combustor helps to reduce emissions of pollutants and improve boiler performances. CFD simulation is first performed on the combustion of coal solely. The results of simulation obtained are then compared to the actual data taken from the Tanjung Bin power plant for validation purpose. Once the data validation has been achieved, second simulation can be performed on the same model for cofiring. The validation indicates that finer grid of meshing produces more accurate results with small error of 6.9% and 7.9% for the validation of temperature and radiation respectively. The results obtained from simulation indicate that cofiring does lower the emissions of CO_2 significantly. This is shown by the concentration of CO_2 that dropped drastically when coal was cofired with biomass. It is very important to reduce the amount of CO_2 concentration in the air through the understanding of these gases formation as it would become a threat to the environment if the level is too high compared to other gases. A more intense combustion can also be achieved that can improve the combustion performance in terms of temperature and radiation. These parameters may indicate better combustion efficiency if the two fuels were burned together.

Keywords: cofiring, coal, biomass

1. INTRODUCTION

Biomass fuel has a great potential in contributing to electric generation in Malaysia. In order to increase the usage of other sources of energy to generate electricity, biomass has been utilized together with coal. The burning of biomass with coal is known as co-firing. Co-firing biomass with coal offers a lot of advantages by reducing the total emissions of poisonous gaseous and has the capability of minimizing pollutions as well as reducing capital costs rather than cofired coal alone. Both coal and biomass are chosen in this study due to the facts that they have great potential to be developed in future for power generation in Malaysia.

The objectives of this study are to study the impacts of burning biomass with coal on the pollutant emissions and to compare the combustion performance of this cofiring type. The scope of this study is to use sawdust as the biomass. For modeling and simulation purposes, commercial CFD code FLUENT software will be used.

Cofiring biomass with coal in existing pulverized fuel boilers offers several advantages both to the environment and performance of the boilers. By a better understanding of the destruction mechanisms in flames, it has become possible to reduce significantly their emissions via combustion process modifications.

This study of cofiring is done using CFD technique. CFD modeling is used to analyze the combustion between coal and biomass. It is an effective tool in identifying and solving problems related to coal combustion. In particular, it can provide insight into the combustion characteristics of biomass and coals. A good understanding of the combustion and pollutant generating processes in the combustor can help to predict the behavior of combustion efficiency and pollutant emissions performance.

Combustion performance can be judged based on its burning efficiency. It can be divided into complete and incomplete combustion. Complete combustion is a process that occurs when the fuel is completely burned to generate byproducts of CO_2, H_2O and energy in the form of heat where the efficiency is the highest. Incomplete combustion on the other hand is a partial burning of fuel that occurs when there is not enough air to react with fuel. This happened when the amount of fuel exceed the amount of air supplied. As a result, the reaction become inefficient and produced other byproducts other than CO_2 and H_2O. The other byproducts include CO, NO_X and even soot in which all of them are considered harmful gases.

Power generation is the main industry that emits most of the pollutant gas of CO_2. This gas has highest concentration if we compare to other greenhouse gases emitted by a power plant. Hence, this study was focused on the CO_2 emissions only. It is very important to study the formation of CO_2 as these gases lead to global warming if the level of CO_2 is too high in the atmosphere.

Other pollutants such as NO_X and SO_X were not considered as there are modern developed technologies available namely SCR, SNCR, low NO_X burner and over-fired air that can abate these pollutants. Therefore, it is more critical in abating CO_2 emissions than other pollutants emitted in power plant.

2. LITERATURE REVIEW

2.1 Potential of coal in Malaysia

There is a high potential in the development of coal mining in Malaysia. Malaysia has huge coal reserves that can be fully tapped as an additional source of energy to lessen the burden of domestic industries currently saddled with increasingly high energy costs from gas and electricity. In Sarawak and Sabah alone, coal reserves are distributed widely which indicates that there is a large supply of coal in the Eastern Malaysia. By 2010, Malaysia's demand for coal is expected to reach 19 million tonnes, according to the Malaysian Chamber of Mines. Efforts should be taken to enhance the supply by exploring potential of developing local sources especially in Sarawak for long term supplies. Development of the coal resources in Sabah and Sarawak should be sufficient to supply a large portion of Malaysia's demand. However, most of the coal areas are located far inland where infrastructure is poor [1].

2.2 Potential of biomass in Malaysia

The use of fossil fuel generates green house gas emissions which leads to global warming and causes climate change. One method of mitigating these environmental impacts is by increasing the fraction of renewable energy used. Biomass offers important advantages as a combustion feedstock due to the high volatility of the fuel and the high reactivity of both the fuel and the resulting char. Furthermore, biomass contains much less carbon and more oxygen and has a low heating value as compared to solid fossil fuels. Depending on the biomass demand of the country, the land area required to meet the demand can be calculated. In Malaysia, the demand for industrial wood is much higher than fuelwood and sawn wood. This indicates that the land areas required to meet the demand is very high and because of this, biomass production of this industrial wood can be expanded throughout Malaysia. An example of this type of industrial wood would be sawdust. Furthermore, the chemical properties of sawdust are quite promising in which it has high value of moisture and volatiles. All these properties help to improve the combustion performance.

2.3 Cofiring

This technology consists of the substitution of a percentage of the fossil fuel normally coal by biomass. Co-firing, when compared to an exclusive use of fossil fuels for which the power plant was designed, presents important advantages mainly on the socioeconomic and environmental impact which stands out to be the best solution by the reduction of CO_2 and NO_x. This technology presents many advantages such as increasing the efficiency of power generation and decrease the investment as it make use of great part of the power plant facilities. The reduction of pollutant emissions depends upon the chemical composition of different biomass used. Furthermore, blending biomass with coal can reduced the CO_2 emission by recycling the CO_2 in the atmosphere. During growth, the biomass absorbed certain amount of carbon dioxide before it emits back to the atmosphere by the same amount of carbon dioxide. Therefore, it does not contribute to the emission of CO_2 and because of that it is known as CO_2 neutral fuel.

2.4 Combustion performance

According to [2], fuel burning systems introduce fuel and air for combustion, mix the reactants, ignite the mixture and distribute the flame envelope and product of combustion. The rate of complete combustion is greatly dependant on the temperature, concentration, preparation and distribution of the reactants by catalysts and mechanical turbulence [3].

A flame is the central reaction zone of a combustion process. The physical characteristics of the flame, such as geometrical and luminous profiles, temperature distribution, and oscillatory attributes, provide instantaneous information on the quality of the fuel and thus the combustion process. Monitoring and quantification of these flame properties are therefore important for deep understanding of the impact of biomass addition into coal on the flame characteristics, fuel conversion and pollutant formation processes, and subsequently the optimisation of the combustion process.

Generally, low heating value will cause low flame temperature during combustion. Reference [4] stated that in the case of low heating values caused by high moisture contents, it will cause low flame temperature. However, this is not the case for low heating values caused by high oxygen contents which are not associated with low flame temperature. In fact, according to reference [5], oxygen enrichment increases the flame temperature, promotes soot formation and oxidation, and can decrease pollutant emissions compared with hydrocarbon-air systems. This presents dissimilar approach from the study by [6] that investigated the impacts on flame characteristics through measurements of main parameters where they found that the much higher volatiles contents of the wood results in a more intense flame which leads to a higher temperature for the combustion. This means that the higher intensity of flame, the better is the combustion performance.

More marked differences are observed between the flames from the biomass and coals. According to reference [6] the much higher volatiles content in biomass results in a more intense flame close to the burner region. It was proven that the combustion zone extends further for biomass while unburnt species were very low for the coals. It follows that two stages can be distinguished in biomass flame where a zone of intense combustion occurs close to the burner followed by second region where large biomass articles gradually devolatilize and are consumed. The combustion intensity in the near burner region grows with the volatile material content of the fuel.

2.5 Pollutant emissions

During coal combustion, pollutants especially CO_2 was released into the surrounding. CO_2 is a greenhouse gas. It is colourless, odourless and are non-toxic gases. However, if the levels are too high in the air, it may become an issue of pollution in which they become the main contributor to global warming. CO_2 was also believed in contributing to ozone depletion causing our earth become warmer. Global warming was very much likely caused by the increasing concentration of CO_2 resulting from human activity such as fossil burning and deforestation. This hazardous pollutant must be reduced to a certain level in order to protect our earth and environment.

3. METHODOLOGY

Actual data were taken from Tanjung Bin power plant for the modeling and simulation processes involving only the performance for temperature and radiation. For the construction of model geometry GAMBIT was used. Only half of the geometry was modeled due to symmetry.

Appropriate mesh size must be generated to the model to obtain accurate results as different mesh sizes created has different impact on the solution to the model. Four meshes were created known as mesh 1, 2, 3 and 4 (Figure 1,2,3, and 4). The coarsest grid was 0.25m, followed by finer grids of 0.125, 0.050 and 0.03125m respectively. The meshing from GAMBIT was exported to FLUENT for the next CFD setup.

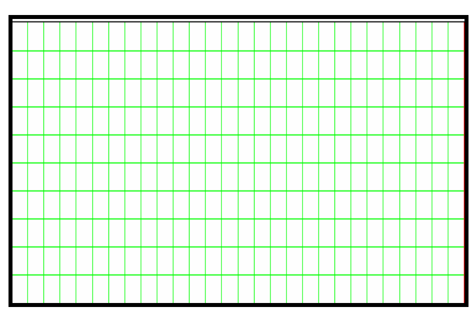

Figure 1: Mesh 1

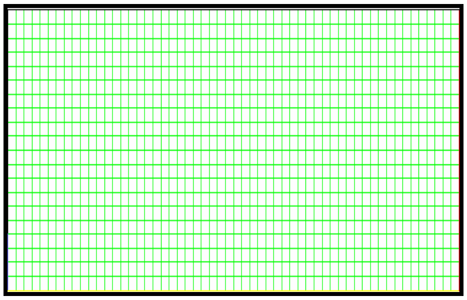

Figure 2: Mesh 2

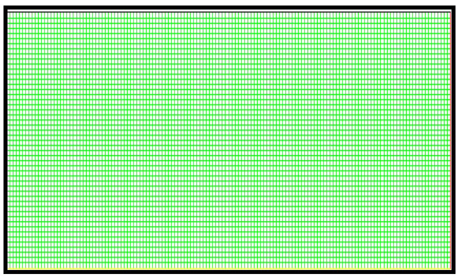

Figure 3: Mesh 3

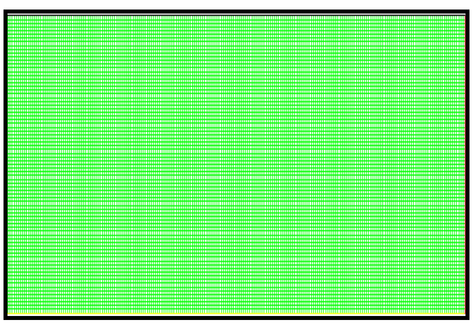

Figure 4: Mesh 4

Once the mesh file was exported from GAMBIT to FLUENT, appropriate model settings were made. The materials used in this simulation must be defined too. The first was a mixture called pdf-mixture and the characteristics were calculated in PDF table. The second material is the coal combusting particle. Property settings related to coal were selected from the list of database options in the Set Injection Properties panel. Then, boundary conditions for each zone of burner were defined based on data from Tanjung Bin power plant. Once everything was defined for the settings, next step would be validation of model.

Model validation is done in two stages which is grid independence test and results validation with previous study works. Simulations were run on four different mesh sizes ranging from 0.25 to 0.03125 in order to determine which mesh size could produce the best results for validation purpose. The model was validated using the data obtained from Tanjung Bin coal power plant. Once the validation of data is done, the same model will be used to identify possible improvement of the boiler performance by means of biomass addition. The validated model was employed to investigate the impact of cofiring coal and biomass on the performance and emission level of pollutants.

4. RESULT AND DISCUSSION

This chapter discusses the outcomes of this study based on the methodology mentioned previously. The geometry of domain was constructed in GAMBIT before exported to FLUENT for simulation. In the construction of geometry, only half the width was modeled due to symmetry. Boundary entities which include walls, axis, velocity inlet and pressure outlet were defined for each of the zones.

Four different meshes were generated for the purpose of model validation. Coal combustion must be validated before any further simulation is to be done to investigate the performances of the burner. Since there were only two data needed for the model validation, therefore only the performance of temperature and radiation will be presented. The actual temperature measured was 814 K while the actual radiation was 19304 W/m^2. Since the values given did not specify exactly where the position of the temperature and radiation took place, hence, the

Table 1: Comparison of temperature value

Grid Spacing (m)	Actual Temperature (K)	FLUENT Temperature (K)	Error (%)
Mesh 1 (0.25m)	814	669	17.8
Mesh 2 (0.125m)	814	714	12.3
Mesh 3 (0.05m)	814	758	6.9
Mesh 4 (0.03125m)	814	792	2.7

Table 2: Comparison of radiation value

Grid Spacing (m)	Actual Radiation (W/m^2)	FLUENT Radiation (W/m^2)	Error (%)
Mesh 1 (0.25m)	19304	13834	28.3
Mesh 2 (0.125m)	19304	20479	6.1
Mesh 3 (0.05m)	19304	20822	7.9
Mesh 4 (0.03125m)	19304	21209	9.9

values were assumed to be the average temperature and average radiation taken during combustion in the burner. The simulation was carried out to obtain area-weighted average which was reported in surface integrals. The results are as shown in Table 1 and Table 2 respectively.

Grid independence test has been done to assure the accuracy of the CFD model to be validated. It was shown from the grid independence test that more accurate results can be achieved when the mesh size is reduced. As the grid spacing decreased, both number of nodes and cells increased tremendously. An error less than 10% is acceptable for model validation. For both cases of temperature and radiation, it appeared that mesh 3 would be more likely to be validated with the small percentage of error less than 10% with 6.9% and 7.9% respectively. Furthermore, there is no significant change or large difference of values when the grid spacing was reduced from 0.05m to 0.03125m. Therefore, mesh 3 of grid spacing 0.05m was chosen because the values of temperature and radiation were not far different from each other. Thus, mesh 3 was used in this model for further study on co-firing coal and biomass.

As the combustion in the burner become more intense, more O_2 will be consumed for the reaction to take place. The consumption of this O_2 will lead to the emission of another gas known as CO_2. Both O_2 and CO_2 are correlated with each other. From Figure 5, it is clear that the amount of CO_2 emitted during cofiring were much lesser compared than the amount emitted during coal combustion as shown in Figure 6.

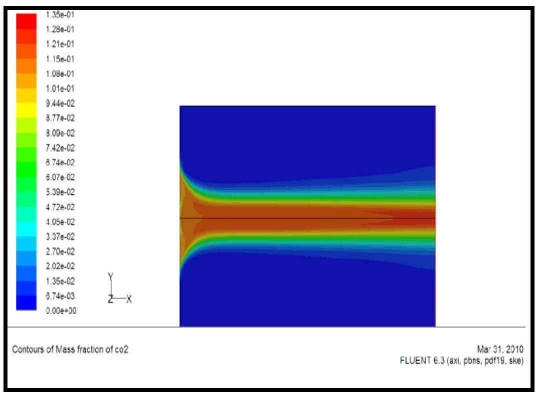

Figure 5: CO_2 mass fraction for cofiring

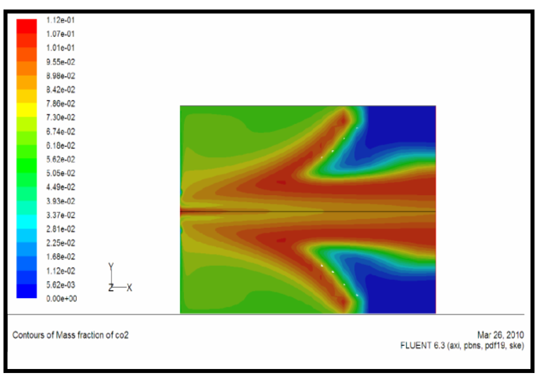

Figure 5 : CO_2 mass fraction for coal combustion

Blending biomass with coal can reduced the CO_2 emissions. This is because the biomass absorbed certain amount of CO_2 before it emits back to the atmosphere the same amount. This recycling of CO_2 in the atmosphere is the reason why the CO_2 emissions become lesser in cofiring. It does not contribute to the emission of CO_2.

Contour of mass fraction O_2 obtained has shown that the concentration of O_2 is very low along the axis where the air and fuel were channeled through the inlet. In this cofiring flame, gas phase combustion is more important, leading to more rapid consumption of O_2 which explain why the concentration drop drastically shown in Figure 7 compared to Figure 8 that shows the O_2 concentration in coal combustion. This low O_2 level is due to the greater progress of combustion in both cases of combustion. Another reason for this rapid combustion is because of the high volatile matter existed in biomass. These parameters may indicate better combustion efficiency if the two fuels were burned together. For these two simulations, both have the highest O_2 mass fraction of 0.233.

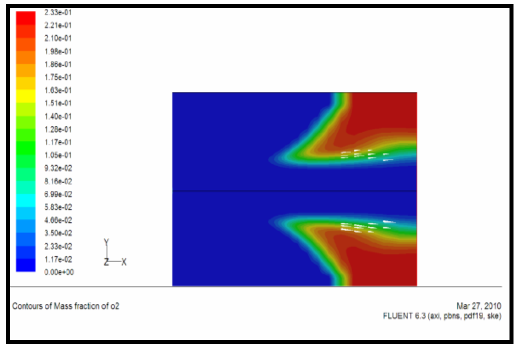

Figure 8: O_2 mass fraction for coal combustion

The flame temperature profile for coal combustion shown in Figure 9 is higher from the center of the burner till it reaches the end of it. Meanwhile, in the combustion of coal and biomass, more intense combustion can be seen as shown in the contour plot of temperature in Figure 10. This intense combustion caused the area along the axis plane which is the center region of burner has higher temperature level compared to the area surrounding it. This type of temperature profile is expected to occur as burning coal and biomass together help to improve the combustion performance.

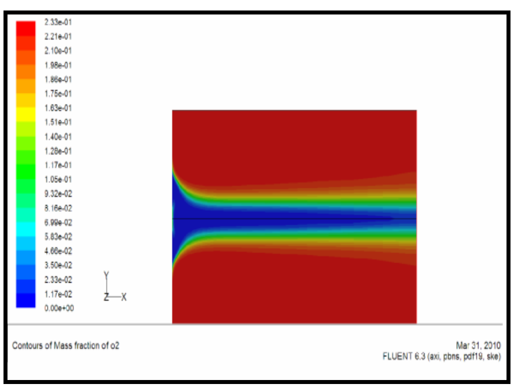

Figure 7: O_2 mass fraction for cofiring

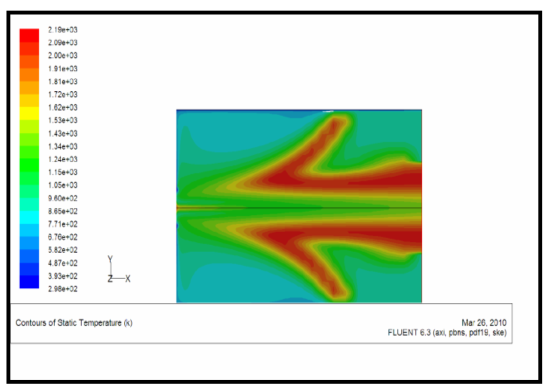

Figure 9: Temperature profile for coal combustion

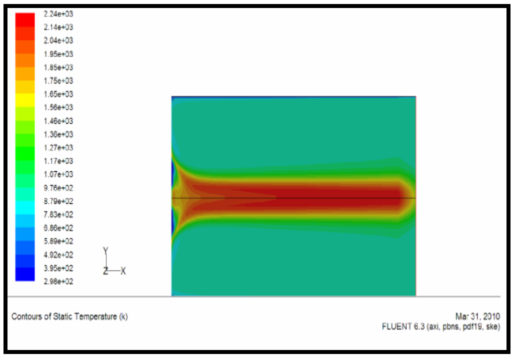

Figure 10: Temperature profile for cofiring

It is predicted that the active combustion does happen at the center region of the burner starting from the mouth of the burner. It is the mouth of the burner where the active combustion took place before it spreads along the axis. Since sawdust particles are much bigger than coal particles, it is expected that the burning would take longer residence time for them to be burned completely. This is as shown in the profile where the length of flame is extended until the exit of the burner.

5. CONCLUSION

5.1 Conclusion

Numerical investigations on the coal combustion and cofiring are presented. Additionally, results of numerical simulations of the coal combustion and cofiring are compared. Combustion has shown that there is a high potential to reduce CO_2 emissions by using coal and biomass as the fuels as well as its combustion performances. It has been confirmed that CO_2 emissions will be reduced when using coal and sawdust together in the combustion system through the simulation done using FLUENT software which showed the lower concentration of CO_2. Due to some of the unavailability of data for simulation, this project is constrained to use sawdust only for cofiring process. From the results of simulation, it seems that cofiring by burning sawdust and coal may have the potential to become an important part of electricity generation in Malaysia in future.

5.2 Recommendation

In this study, only sawdust was used to be cofired with coal in the combustion chamber. In future, it is recommended that different type of biomass can be studied for the investigation of impacts on combustion performances and emissions of pollutants. Variety of biomass can be found in Malaysia that can be used for further study involving the CFD software. There is a lot of governments can do to contribute in the reduction of pollutant emissions resulted from the combustion process. The government can invest on a cleaner technology to produce electricity because if we rely heavily on coal alone, this can produce a lot of adverse effects on the environment. Another recommendation is related to the technology of computers. Simulation using FLUENT software can be improved with the usage of a higher ram computer to reduce the computing time needed for convergence to be achieved.

6. REFERENCES

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