

Effect of Residual Cake Steryl Glucoside Co-Firing on Boiler Combustion, Efficiency, and Fuel Cost

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ABSTRACT

Steryl Glucosides (SG) are compounds produced from the processing of Fatty Acid Methyl Ester (FAME). SG compounds are obtained from the FAME filtration process using filter aid media. The filtering process produces residue in solids mixed with SG compounds (residual cake SG). Previous studies have shown that SG has a high calorific value and good combustion characteristics. However, the research is still on a laboratory scale. On the other side, another study states that implementing co-firing on boiler could increase the boiler efficiency and reduce the fuel cost. These previous studies indicate that residual SG cake has strong potential to be utilized as a secondary co-firing fuel in boilers. Therefore, this study aims to determine the effect of the residual cake SG co-firing ratio on the combustion, efficiency, and fuel cost of the stoker boiler. The trial was conducted directly on the stoker boiler with a ratio of residual cake SG 5 wt%, 10 wt%, and 15 wt%. First, boiler combustion inside the furnace will be studied, then followed by an analysis of boiler efficiency and fuel costs. Based on the trial, increasing the residual cake SG ratio will improve the boiler combustion, increase efficiency, and reduce the fuel cost.

Keywords: steryl glucoside, co-firing, boiler efficiency, fuel cost.

INTRODUCTION

Climate change is one of the most discussed global issues in recent years. Climate change is causing seawater temperatures and levels to rise [1]. Rising seawater levels could inundate land and disrupt activities and ecosystems in the region. It is well known that carbon emissions are the main factor causing climate change [2]. To address this, a number of countries have agreed to commit to reducing carbon emissions through the Paris Agreement [3]. One of the outputs of the agreement is to realize Net Zero Emissions.

Net Zero Emission (NZE) is a condition when the amount of carbon released into the atmosphere does not exceed the amount of emissions that can be absorbed by the earth [4]. Achieving this requires efforts to reduce the production of carbon emissions resulting from various activities. Coal is a major contributor to the accumulation of CO₂ in the atmosphere. Previous studies have suggested that reducing coal consumption could significantly reduce carbon emissions and ensure environmental sustainability [5]. Various ways can be done to minimize coal fuel consumption, one of which is by mixing coal with other alternative fuels, known as co-firing.

Co-firing, also known as co-combustion, is the process of burning two different types of fuel in the same combustion system [6]. This method is generally done by combining coal with other alternative fuels. The advantage of a co-firing system is that it is easy to apply to the boiler without the need to make significant modifications [7]. In addition, previous studies have shown that implementing co-firing is known could increase the boiler efficiency and reduce the fuel cost [8], [9]. Some alternative fuels that have been tested for co-firing in boilers include wood pellets, wood chips, palm kernel shell and spent mushroom substrate (SMS) [8], [10], [11]. Each alternative fuel has its own characteristics so that it gives different results when applied in the boiler.

In the downstream palm oil processing industry, one of the derivative products of palm oil is biodiesel. Biodiesel is a mixture of Fatty Acid Methyl Ester (FAME) synthesized through the transesterification of oils and fats with short-chain alcohols [12]. This process produces a by-product in the form of a precipitate called Steryl Glucosides (SG) [13]. These SG compounds can harm

vehicle engines, so they need to be separated from the main product. The separation of SG compounds from FAME takes place in the cold filtration process using absorbent media [14]. The filtration process will then produce a residue in the form of solids (residual cake), and it is no longer used [15]. Based on previous research, it is known that SG has good combustion characteristics and a high calorific value [16]. However, these studies are still small in scope on a laboratory scale. Therefore, in this research, a co-firing trial using Residual Cake SG in the boiler unit will be conducted.

The research will be conducted using the direct co-firing method, where primary and secondary fuels are mixed and fed directly into the boiler furnace [17]. The research will be conducted gradually at co-firing ratios of 5 wt%, 10 wt%, and 15 wt% residual cake SG. At first, the co-firing ratio's effect on the boiler furnace's combustion process will be studied. Then continued with a study on the effect of the co-firing ratio on the boiler efficiency and the fuel cost. So overall, this study aims to analyze the effect of residual cake SG co-firing ratio on boiler combustion, efficiency and fuel cost.

RESEARCH METHODS

Materials

The specifications of the boiler used in this research are shown in Table 1. Meanwhile, the terminology of the boiler is presented in Figure 1 below. Both information are based on the manual book provided by the manufacturing company.

Table 1. Boiler specification

Description	Result	Unit
Boiler Capacity	20	tph
Boiler Maximum Pressure	18	barg
Boiler Working Pressure	13.5-14.5	barg
Medium	Saturated Steam	-
Boiler Type	Stoker/Chain Grate	-

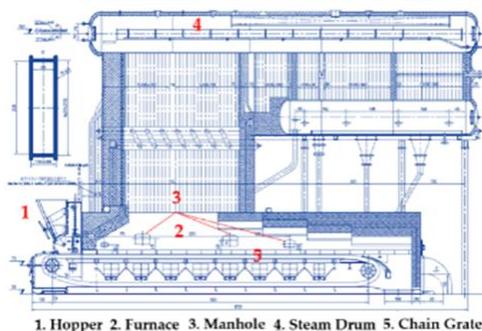


Figure 1. Terminology of boiler

The materials used as a primary and secondary co-firing fuel in this research are coal and residual cake SG. The coal and residual cake SG used belongs to the downstream of palm oil processing industry, where this study was conducted. Below is the appearance of the secondary fuel, the residual cake SG (Figure 2).



Figure 2. Residual Cake SG

Methods

The testing method used in this study is a direct co-firing method. This method is done by blending coal with residual cake SG and putting it into the boiler furnace. The co-firing trial is conducted gradually on a ratio of coal: residual cake SG (95%: 5%), (90%:10%), and (85%:15%) percent weight. This type of research is a kind of field study, where testing is carried out directly on a boiler that normally runs and supplies steam to the production plant. While running normally, the critical parameter to consider is the steam pressure. The steam pressure required by the production plant is 13.50 – 14.50 barg. Therefore during trial, the steam pressure will be monitored continuously.

On the boiler side, the control system for Forced Draught Fan (FDF) and Induced Draught Fan (IDF) will be set to a fixed value. The chain grate speed will be adjusted based on the fuel calorific value to achieve the steam working pressure range. At first, as the trial runs, the combustion process inside the boiler's furnace will be observed. Then, the steam flow and pressure output will be recorded as supporting data related to the combustion. Other boiler parameters, such as fuel consumption and feed water, will also be recorded during the trial. This data will be used to analyze the boiler efficiency and fuel cost on each co-firing ratio. Detailed diagrams are shown in Figure 3 below.

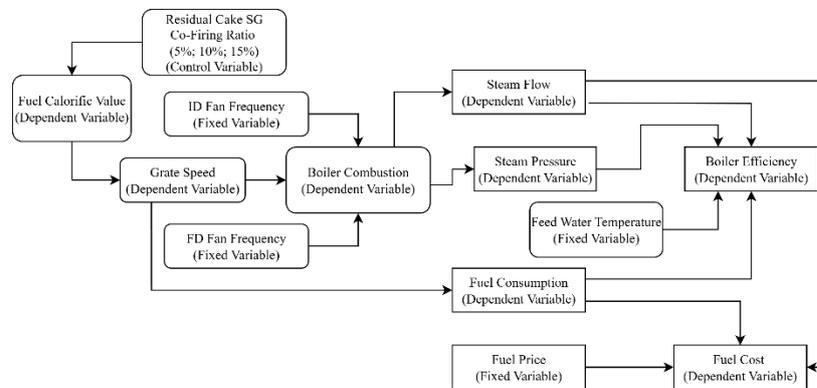


Figure 3. Co-Firing testing variable diagram

Data Analysis

A. Combustion

Combustion analysis begins by comparing the visual combustion of each co-firing ratio in the furnace. After that, supporting data such as pressure and flow of steam produced are also analysed.

B. Boiler Efficiency

Analysis of boiler efficiency using the direct efficiency calculation method. This method is used because it is by the tests carried out, which examine the energy increase of the working fluid produced and compare it with the energy content of the fuel. This method is known as the input-output method to evaluate the boiler efficiency [18]. The calculation formula of direct efficiency is as follows:

$$\text{Direct Efficiency} = \frac{\text{Steam produce} \times (\text{enthalpy steam} - \text{feedwater})}{\text{Fuel consumption} \times \text{Calorific Value}} \times 100\% \quad (1)$$

All the data required for the calculation are taken from the co-firing testing for each ratio.

C. Fuel Cost

Analysis of fuel cost will be done by multiplying the fuel price and Specific Fuel Consumption (SFC). The calculation formula for fuel cost is as follows:

$$\text{Fuel Cost} = \text{Fuel Price} \times \text{SFC} \quad (2)$$

$$\text{SFC} = \frac{\dot{m}_{\text{fuel}}}{\dot{m}_{\text{steam}}} \quad (3)$$

$$\text{Fuel Cost} = \frac{P_{\text{fuel}} \times \dot{m}_{\text{fuel}}}{\dot{m}_{\text{steam}}} \quad (4)$$

$$\text{Fuel Cost} = \frac{(P_{\text{coal}} \times \dot{m}_{\text{coal}}) + (P_{\text{RCSG}} \times \dot{m}_{\text{RCSG}})}{\dot{m}_{\text{steam}}} \quad (5)$$

Where:

\dot{m}_{fuel} = fuel flow rate (ton/hour)

\dot{m}_{coal} = coal flow rate (ton/hour)

\dot{m}_{RCSG} = residual cake SG flow (ton/hour)

\dot{m}_{steam} = steam flow rate (ton/hour)

P_{fuel} = fuel price (IDR/ton)

P_{coal} = coal price (IDR/ton)

P_{RCSG} = residual cake SG price (IDR/ton)

All the data required for the calculation are taken from the co-firing testing for each ratio. Then, the fuel cost result will be shown in a graph for each co-firing ratio.

RESULT AND DISCUSSION

The Co-Firing Testing

The co-firing testing is conducted directly on the boiler unit to see the combustion effect. A co-firing trial was conducted at ratios of 5 wt%, 10 wt%, and 15 wt% residual cake SG. The visual condition of combustion inside the boiler furnace was observed. On the other side, the supporting data, such as steam pressure and flow, were being recorded during the trial. All this data will be used to analyze the combustion effect. Below is the explanation of the co-firing trial.

At the beginning, the baseline data was also taken as a reference for this trial. The baseline data was taken based on the boiler operating condition using 100% coal. At this moment, the fixed variables such as FD and ID fan frequency were set. These values will be the same in other co-firing ratios. The baseline data was then compared to the other co-firing ratios to see the effect of the residual cake SG addition. Figure 4 is the result of baseline data. In the middle section, the flame is evenly filling the boiler furnace. Otherwise, on the front and rear sections the flame is not evenly distributed.

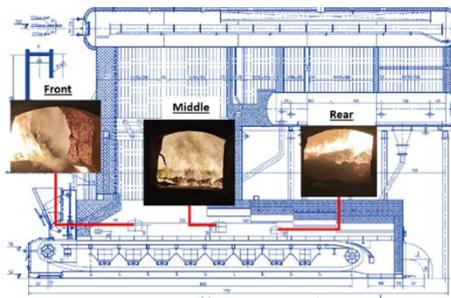


Figure 4. Combustion visual appearance of the baseline

Next, the co-firing testing is conducted for the ratio of residual cake SG 5%, 10%, and 15%. The result is shown in Figures 5, 6, and 7. Based on the trial, it is shown that the combustion inside the boiler furnace is getting better as the co-firing ratio increases. The combustion flame on the front and rear section is become evenly distributed. This shows an improvement in boiler combustion compared to the baseline.

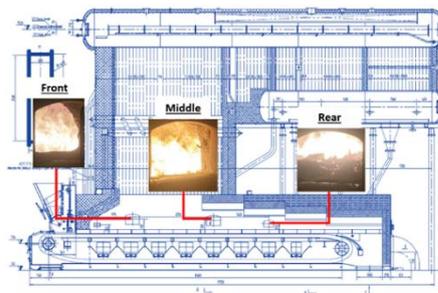


Figure 5. Combustion visual appearance of residual cake SG 5%

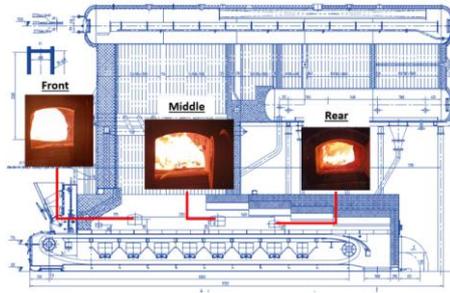


Figure 6. Combustion visual appearance of residual cake SG 10%

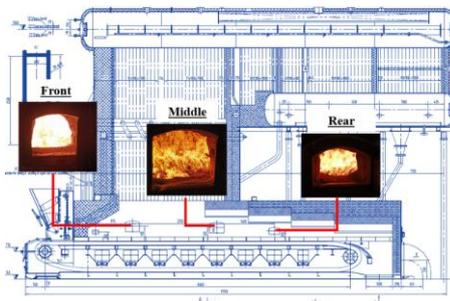


Figure 7. Combustion visual appearance of residual cake SG 15%

The Fuel Calorific Value

Calorific value is the energy content of a fuel per unit mass. In the context of combustion, the heating value is the amount of heat energy that the fuel will release during the combustion process [19]. In other words, the higher the calorific value of the fuel, the more heat energy can be utilized to convert water into steam.

In conducting the co-firing trial, knowledge of the heating value of the fuels used is important. Knowing the heating value of primary and secondary fuels could help in determining hypotheses and analyzing test results. To determine the calorific value of a fuel, a laboratory test is required. The fuel samples are tested in the laboratory using bomb calorimeter device. The following is the result fuel calorific value.

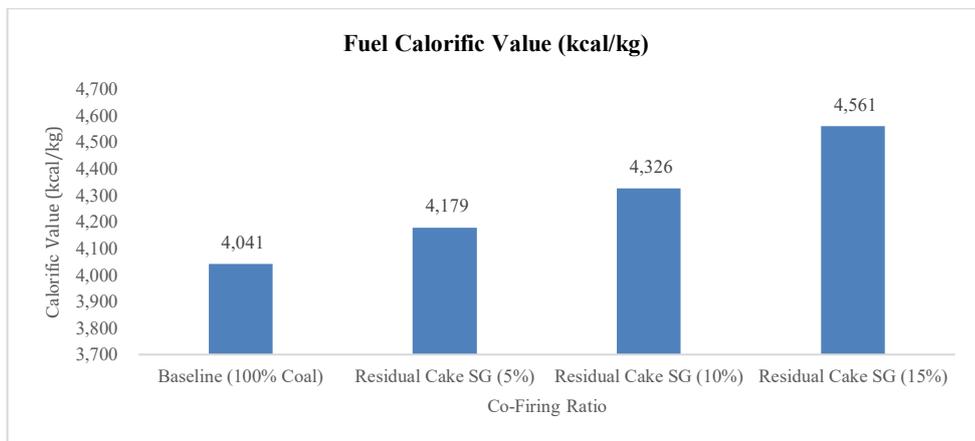


Figure 8. Fuel calorific value

Based on laboratory analysis, as the residual cake SG ratio increases, the fuel calorific value also increases. This is due to the SG having a high calorific value compared to coal [16]. The high

calorific value of SG came from its characteristic which has a high energy density [20]. Otherwise, it was also found that the residual cake SG itself has an oil content. This oil is remaining FAME, which is absorbed by filter aid in the filtration process. Through laboratory analysis, the oil content of the residual cake SG is 47 wt%.

The presence of oil content in residual cake SG also becomes one of the factors which influence the co-firing fuel calorific value. During the blending process of the coal and residual cake SG, the oil content in the residual cake SG could be absorbed into the coal pores. The higher the residual cake SG ratio, the more oil content is absorbed into the coal pores. This affects the increase in overall fuel calorific value [21].

Dicussion of Co-Firing Trial Result

Based on the trial, the visual appearance of the combustion inside the boiler furnace is getting better as the co-firing ratio increases. The fire on the front, middle, and rear furnaces flared up as the ratio of residual cake SG increases. On the front and rear section, it can be seen that the appearance of combustion is increasingly widespread and evenly fills the combustion chamber. This is due to the characteristic of SG, which has a faster initial burn time and longer burning time [16]. Meanwhile, the steam pressure and steam flow result are shown as follows.

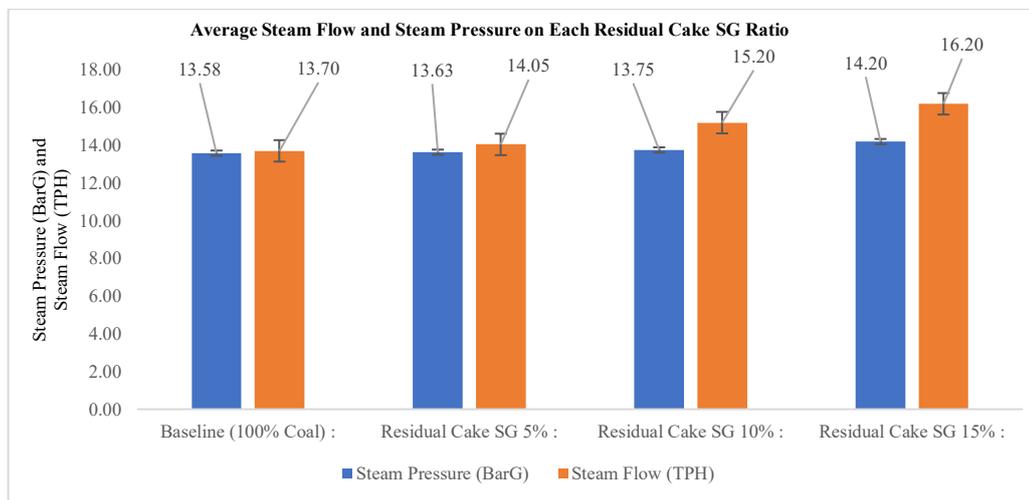


Figure 9. Steam flow rate and pressure graph

Based on the graph, the average steam flow rate and pressure produced by the boiler increase as the residual cake SG ratio increases. This is due to the fuel calorific value also increasing. Increasing the fuel calorific value will lead to an increase in the energy produced by the boiler. In other words, the increasing residual cake SG ratio will lead to an increase in the energy produced by the boiler, such as steam pressure and steam flow rate [22].

Boiler Efficiency

The boiler efficiency analysis uses the direct method. This method is used due to in accordance with the co-firing trial, which examines the increase in steam output and compares it with the energy content of the fuel. Moreover, the advantages of using the direct efficiency method are that the boiler efficiency can be quickly determined and does not require too many instruments [23]. To calculate the boiler efficiency, use equation 1.

Data on steam mass flow rate, fuel flow rate, and heating value were taken based on the test results of each co-firing residual cake SG. The fuel calorific value data is taken from each co-firing ratio. The steam enthalpy data is taken from the steam table based on the vapor pressure readings of each co-firing ratio. Feed water enthalpy data is taken from the steam table in the saturated water phase based on the boiler feed water temperature. The boiler feed water temperature itself has been set

under normal operating conditions at 95 °C. By using these data, the efficiency value of the boiler stoker is shown in Figure 10.

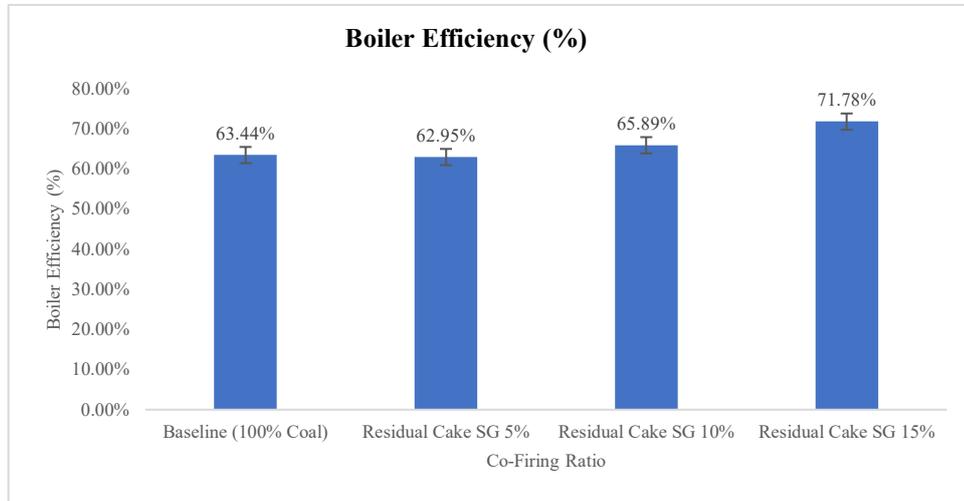


Figure 10. The boiler efficiency graph

Based on the graph, the boiler efficiency value at a residual cake SG ratio of 5% appears to decrease compared to the baseline. However, the decreasing efficiency does not significant due to the difference in the value of the numbers behind the comma. This is because the energy output produced at the two ratios is not much different, while the heating value of the fuel used at the 5% residual cake SG ratio increases. In other words, the use of a 5% residual cake SG co-firing ratio does not give a significant effect on boiler efficiency.

Meanwhile, the boiler efficiency values at 10% and 15% SG residual cake co-firing ratios were seen to increase. This is due to the increase in energy output produced at both ratios. The increasing co-firing ratio will increase the heating value of the fuel [24]. The increasing calorific value of fuel will have an impact on increasing boiler efficiency. In other words, an increase in the co-firing ratio of residual cake SG by 10%-15 % will increase the efficiency of the boiler. Hence, the more the co-firing ratio increases, the boiler efficiency also increases.

Fuel Cost

To determine the effect of the co-firing ratio of residual cake SG on fuel costs, calculations were made based on co-firing trial data. The formula used to calculate fuel cost is equation 2, which elaborates more on equation 5. The coal price is taken from an internal report, while the residual cake SG is free. The steam produced and fuel consumption were taken from the co-firing trial results. The result of fuel cost estimation on each co-firing ratio is shown in Figure 11.

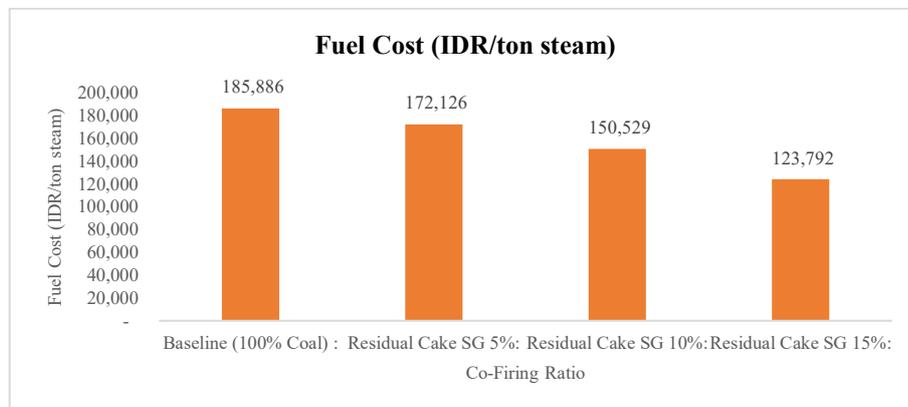


Figure 11. Fuel cost graph

Based on the calculation, the fuel cost will decrease as the co-firing ratio of SG residual cake increases. This is due to two factors: the price and calorific value of residual cake SG. First, the residual cake SG is free and obtained from the biodiesel plant. This causes the result of multiplying the price by the quantity of fuel to be zero. As a result, the fuel cost value will decrease as the co-firing ratio increases.

Then the second factor is the higher calorific value of residual cake SG than coal. Therefore, as the co-firing ratio of SG residual cake increases, the overall heating value of the fuel will increase as well. The increase in the heating value of the fuel will have an impact on increasing the amount of steam energy produced by the boiler [22]. Overall, the results of the fuel cost calculation are in line with the statements from previous co-firing research. The study states that fuel costs will decrease if the secondary fuel used has a lower price and higher heating value than the primary fuel [9].

Final Result

After conducting a co-firing test and analyzing boiler efficiency and fuel costs, the final results indicate that a higher co-firing ratio of residual SG cake leads to improved boiler combustion, higher boiler efficiency, and lower boiler fuel cost.

CONCLUSION

Based on the trial result of co-firing residual cake SG 5%, 10%, and 15%, the conclusions are: 1) implementing the residual cake SG as a secondary co-firing fuel will improve the boiler combustion. This is indicated by the combustion visual appearance inside the boiler furnace. As the co-firing ratio of residual cake SG increases, the fire flame becomes evenly distributed, and the pressure and mass flow rate of the steam produced also increase, 2) implementing the residual cake SG as a secondary co-firing fuel will increase the boiler efficiency. This is due to the residual cake SG has a high calorific value. Consequently, the boiler energy output increases as long as the co-firing ratio increases, 3) implementing the residual cake SG as a secondary co-firing fuel will reduce the boiler fuel cost. This is due to the residual cake SG has a higher calorific value than coal and was obtained for free. These two factors will lead to a lower boiler fuel cost.

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