Characteristics of medium-low rank coal blending on performance and efficiency steam power plant

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Abstract. Blending medium rank coal (MRC) with low-rank coal (LRC) is carried out to meet the caloric content which follows the boiler specifications. Negative effects of blending with LRC are environmental, specific fuel consumption (SFC), and efficiency issues. The purpose of this research is the optimum blending composition of LRC and MRC coal, which can be used by power plants. The research methodology used is to simulate coal blending with MRC percentage in the MRC-LRC from 0, 20%, 40%, 50%, 60%, 80%, and 100%. The type of coal used is categorized in MRC1, MRC2, LRC1, LRC2, LRC3. The combination used is MRC1-LRC1, MRC1-LRC2, and MRC2-LRC3. From the analysis obtained, if the MRC percentage in MRC-LRC blending increases, losses will decrease mass flow will decrease, SFC will decrease, and boiler efficiency will increase. Blending MRC2-LRC3 has the lowest losses, low mass flow with an average of 298.78 ton/h, low SFC with an average of 0.466 kg/kWh, and boiler efficiency between 84.85% to 85.71 %. Blending MRC2-LRC3 is most recommended for use in combustion plant with a minimum MRC2 percentage of 50%.

Keywords: coal blending, medium rank coal, low rank coal, boiler efficiency

1. Introduction

At present the need for fuel generation power plant in the word 36 % comes from coal fossil fuels [1]. Some countries in the world, most still use coal fossil fuels, such as South Africa 93%, Poland 92%, China 79%, and Australia 77% [2]. In general, power plant is designed with coal fuel which has a specific composition and heating value. Coal will be blending to meet boiler specifications. The caloric value of coal mining product in Indonesia is generally of low quality anthracites 0.3 %, bituminous 13%, sub-bituminous 26.7%, and lignite 58.7% [3]. Blending coal quality is basically a combination of all coal parameter, in order to get high boiler efficiency [4]. Optimization of coal blending depends on the method and equipment, stockyard size, coal quality distribution, coal management quality control system, and sustainable coal procurement inventory system [5]. In conducting coal blending there are several reasons that are reducing electricity production cost, guarantee of electricity supply for consumers, according to specifications of power plant, regulation on emissions and pollutant [6]. Optimization of coal blending can be increase coal quality diversity, stability of electricity production. Coal blending also helps solve coal transportations problems [7].

From the results of research it has been obtained, coal blending Cibabuyun Garut, Adaro South Kalimantan, Bayah Lebak Banten still produce high emissions, emission pollutant volatile matter is high
[8]. The results of the optimization of blending low rank and high rank coal with a ratio of 80:20 can reduce electricity productions cost to 342 IDR/kWh [4]. Other indicators of combustion from coal blending can be seen from the heat value, volatile matter, melting point, ash content, and high sulphur levels will be cause corrosion [9], and high heating value an impact on boiler efficiency [10–12]. Calculation of boiler efficiency with the heat loss method helps to identify the sources of heat losses [10]. Environmental issues that are always associated with combustion in plants are Carbon Dioxide (CO2), Nitrogen dioxide (NOx), Sulphur Dioxide (Sox) emissions. The percentage of unburned carbon decreased the impact is NOx emissions level increase if that percentage of sub-bituminous coal rises and the percentage of unburnt carbon rises. So that increase in NOx can be estimated from unburnt carbon levels [13–16]. Indonesia Power Company UP Surayala (UPS) is power plant with coal fuel a capacity of 3400 MW, coal received has a different heating value, can be grouped type of medium rank (sub-bituminous) and low rank. So that the caloric value of the coal fed to the boiler meets requirements, the coal will be blending. This study was conducted to determine the effect of medium rank and low rank coal blending percentage on boiler efficiency.

2. Methodology

In this research the coal blending uses method by Canterper, and approach taken by Jianbo Li, et.all [16], coal blending is based on proximate analysis, ultimate analysis as shows in table 1, data obtained from UPS. In table1, MRC is medium rank coal, and LRC is low-rank coal. While the blending composition of percentage used in this research 0% MRC, 20% MRC, 40% MRC, 50% MRC, 60% MRC, 80% MRC dan 100% MRC. The boiler efficiency method is calculated according to ASME PTC 4-1 standard and heat loss approach [10], i.e.

\[ \eta = 100 - L_1 - L_2 - L_3 - L_4 - L_5 - L_6 - L_7 \]  

(1)

where,  

\( L_1 \): losses form dry exhaust gas  
\( L_2 \): losses moisture from burning hydrogen  
\( L_3 \): losses moisture in coal fuel  
\( L_4 \): losses moisture in the air  
\( L_5 \): losses form imperfect combustion  
\( L_6 \): losses from radiation and convection are assumed is 0.19 % [10].  
\( L_7 \): losses from carbon does not burn are assume is 1 %.

Same advantages using the heat loss method include more easily calculate losses by measuring the coal mass flow rate, easy to check losses for are controlled and uncontrolled losses, boiler efficiency can be increased by knowing the type of losses [17].

| Parameter                        | MRC1 | MRC2 | LRC1 | LRC2 | LRC3 |
|----------------------------------|------|------|------|------|------|
| Proximate analysis (wt. %)       |      |      |      |      |      |
| Moisture                         | 24.23| 24.44| 28.49| 26.15| 28.16|
| Ash content                      | 5.09 | 5.21 | 4.92 | 2.22 | 4.73 |
| Fixed carbon                     | 37.02| 35.90| 33.71| 34.28| 34.04|
| Volatile matter                  | 33.66| 34.45| 32.88| 37.55| 33.07|
| Ultimate analysis (wt. %)        |      |      |      |      |      |
| Carbon                           | 53.76| 53.09| 50.55| 53.85| 51.97|
| Hydrogen                         | 3.75 | 3.72 | 3.54 | 3.48 | 3.71 |
| Oxygen                           | 11.20| 11.63| 11.38| 13.51| 10.37|
| Nitrogen                         | 1.09 | 1.08 | 0.77 | 0.71 | 0.78 |
| Sulphur                          | 0.87 | 0.84 | 0.34 | 0.18 | 0.28 |
| HHV (kcal/kg)                    | 5109 | 5041 | 4888 | 4821 | 4920 |
3. Results and Discussions

3.1. Proximate, ultimate, and calorific value analysis

From the proximate and ultimate test results that need attention are ash content, nitrogen, sulphur content can cause corrosion [9]. On the hand the company has set standards for ash content nitrogen and sulphur content. Effect of ash content on boiler will reduce the flame in heat exchanger, increase excess air, increase in exhaust gas [18]. Company has implemented a maximum standard of ash content in coal is 5% by weight. Based on Figure 1, MRC1-LRC1, MR1-LRC2 and MRC2-LRC3 coal blending meets the maximum ash content limit requirement of 5%, if the percentage of MRC content increase, the ash content in coal also rises, this results of this research are corresponding to the results of the study [11]. MRC1-LRC1 and MRC2-LRC3 coal blending is recommended for combustion in boiler.

Figure 1. Effect Percentage MRC-LRC to ash content

Figure 2. Effect Percentage MRC-LRC to Nitrogen content

Figure 2 shows the amount of nitrogen in coal based on analysis proximate test; company has determined that the nitrogen in coal is maximum 1.11% by weight. Nitrogen in combustion will potentially produce NOx exhaust emissions, the higher the nitrogen in coal, the higher the potential NOx emissions. This results will be relevant to the results of research form [13,15,19]. From Figure 2, it can also be seen that if the percentage MRC increase, the weight nitrogen in coal also rises, this relevant to study [11], where the MRC-LRC percentage has a linier relationship with nitrogen in coal.

Figure 3. Effect Percentage MRC-LRC on sulphur

Figure 4. Effect Percentage MRC-LRC on Heating Value
From Figure 3, shows the relationship between percentage of MRC on sulphur, if percentage MRC rises, the sulphur content also rises. Sulphur in coal will cause corrosion in boiler pipes [9], then the company set the standard sulphur in coal between 0.4% to 0.6% by weight. Coal blending with a percentage of 20:80 to 60:40 meets the sulphur content standard in coal. If percentage of MRC in mixture rises, the sulphur content in coal also rises, this has an impact on increasing Sox emission levels. Results of this research are relevant to results of research from [7,11].

Figure 4 shows that the relationship of proportion of MRC-LRS to caloric value of the coal blending. The company has set a permissible caloric between 4900 kcal to 5100 kcal/kg. Based on Figure 4, the percentage of at least 20% MRC meets the caloric value coal requirement to be fed the boiler. Each increase percentage of MRC, caloric value in coal also increase, meaning that caloric value has linear relationship with increase percentage MCR in coal blending. The results of this study are relevant to results of study [11,20] which states that if percentage of MRC in coal blending rises and carbon content in mixture rises, then the HHV coal also rises.

3.2. Analysis Losses

Based on the results of data processing, that three losses that have percentage of more than 1%, that is L₁, L₂, and L₃. If the percentage of losses from unburned carbon increases, the efficiency of boiler decreases, and each increase of carbon burned rises between 5%-8%, the efficiency of the boiler will be decrease by 2% [21].
In Figure 5, shows influence of percentage of MRC1-LRC1 on losses. With the simple linear regression method, gradient for $L_1$ is 0.0007, average of losses 5.74 %, gradient for $L_2$ is 0.0003 and average of losses 4.48%, and gradient for $L_3$ is -0.0055 with average of losses 3.372 %. From the gradient difference its can be said the percentage of blending MRC10-LRC1 does not effect, on the amount of dry gas exhaust losses, and moisture in hydrogen combustion process, but the influence on the moisture losses in coal.

Form Figure 6, average L1 and L2 losses for MRC1-LRC2 blending are, respectively is 6.49% and 4.54%, and from Figure 7, average L1 and L2 losses for MR2-LR3 blending are, respectively is 61.18% and 4.64%. The L1 and L2 losses does not have a linear relationship with the MRC-LRC percentage increase. While the L3 average losses for MRC1-LRC2 and MRC2-LRC3 are respectively 3.59% and 3.73%. L3 losses have linear relationship with MRC-LRC where each gradient is -0.017 and -0.005, the meaning that if percentage of MRC-LRC in blending rises, losses due to moisture in coal will be reduced. The results of this research are relevant to the results of the study [4, 22], which states that if the quality of coal in blending increase, then the losses from combustion moisture will decrease.

3.3. Mass flow, SFC and Boiler Efficiency Analysis

Efficiency is basically the ratio of energy out compared to the energy input in a system. Boiler efficiency is ratio of boiler output production compared to the input rate[18]. Boiler efficiency can be improved through combustion optimization by increasing carbon and caloric value in coal blending [13]. On the other hand by reduction the rate mass of coal fed to boiler will reduce the cost electricity production [4]. Figure 8, coal mass rate has an inverse linear relationship with MRC-LRC percentage. This means that if percentage of MRC in coal blending increase, the mass of coal will go down. Reduction coal mass flow rate is relevant to results the study [10,11,22]. With the linear regression approach, gradient of MRC1-LRC1 is -0.0821, gradient MRC1-LRC2 is -0.0821 and gradient MRC2-LRC3 is -0.38 with average mass flow 297.87 ton/h, its means the use of MRC2-LRC3 coal blending has impact on the use coal mass flow [4].

![Figure 9. Effect percentage of MRC-LRC on SFC](image)

Specific fuel consumption (SFC) is the amount of mass fuel flow need to produce power per hour for one hour. Figure 9, if percentage of MRC in coal blending increase, SFC decrease. The lowest average SFC is a mixture MRC2-LRC3 which is 0.4664 kg/kWh. This mean that fuel demand for coal mass flow decrease, if there is an increase in the heating value, which relevant to the results [10]. The reduction in SFC will have an impact on the reduction in electricity production costs, relevant to results of study [4]. This it is recommended to use MRC2-LRC3 coal blending to feed to the boiler.

![Figure 10. Effect percentage of MRC-LRC on boiler efficiency](image)
Figure 10, that boiler efficiency has a linear relationship on increase MRC percentage in MRC-LRC blending, and correlation is positive. This means that if percentage of MRC in blending increase, the boiler efficiency will also increase. Boiler efficiency increase, if coal quality increase, this is relevant to results of study [10,22]. The minimum boiler efficiency MRC1-LRC2 is 84.95%, and maximum MRC1-LRC1 is 76.21%. With the linear regression approach, greatest gradient is the MRC-LRC3 pair, increasing efficiency it will have an impact the use of coal mass flow, so it will reduce the decrease in production costs. The recommended coal blending is MRC2-LRC3 pair with a composition of least 50% MRC2.

4. Conclusion
Based on the research results, it can be concluded that if the MRC percentage in MRC-LRC blending increases, losses will decrease mass flow will decrease, SFC will decrease, and boiler efficiency will increase. Blending MRC2-LRC3 has the lowest losses, low mass flow with an average of 298.78 ton/h, low SFC with an average of 0.466 kg/kWh, and boiler efficiency between 84.85% to 85.71 %. Blending MRC2-LRC3 is most recommended for use in combustion plant with a minimum MRC2 percentage of 50%.

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