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Comparative Analysis of Coal Quality across Various Coal Basins in Sumatra: A Case Study of Calorific Value, Moisture Content, and Sulfur Content

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Abstract

Indonesia and other countries have used coal as their main energy source for many years. Due to variances in coal formation, maturity, and geological history, each basin may have a range in coal quality. It houses unique coal basins—South Sumatra, Central Sumatra, Riau, and Aceh—each marked by distinct geological features. Variations in coal formation, maturity, and geological history contribute to quality differences. The analysis of coal quality plays a crucial role in determining its suitability for various applications, including power generation, industrial processes, and export purposes. This study focuses on the coal characteristics of Riau (Coal A), Bengkulu (Coal B), South Sumatra (Coal C), and Jambi (Coal D), evaluating parameters such as calorific value, moisture content, and sulfur content. Employing ASTM-based analysis methods, results reveal that Coal D exhibits the lowest sulfur but has a diminished calorific value, while Coal A boasts a higher calorific value but the highest total sulfur content. Understanding such distinctions is crucial for determining coal's suitability for diverse applications like power generation, industrial processes, and exports. Hopefully, this research could help in estimating the economic potential of these basins, identifying areas with higher-quality coal, and planning future exploration and development activities.

Keywords: calorific value, coal characteristics, sumatera coal, sulfur analysis, total moisture

INTRODUCTION

The energy needs in Indonesia continue to increase from year to year. This condition encourages the government to be more creative in managing and utilizing available energy sources more wisely (Talla et al. 2013; Malle et al., 2014; Sutapa et al., 2014 Gani Rachim et al., 2017). One way is in the handling and utilization of coal in Indonesia. Coal is widely recognized for playing a significant part in Indonesia's mining sector. Indonesia is well known as one of the top exporter nations since its supply is consistently growing by approximately 17% per year and contributes nearly 20% of all trade on the global market each year (Rosyid and Adachi, 2016).

Coal is one of the fossil fuels formed from organic deposits where the main elements consist of carbon, hydrogen, and oxygen. The way coal in each mine is formed goes through lengthy process, besides being influenced by scientific factors that know no time limit. It is this formation process that affects the number of impurities contained in the coal so that it affects the quality of the coal itself (Purnomo, Syaiful, and Gazali, 2023). The main application of coal in Indonesia is largely for the production of electricity. In 2016, the Center for Mineral, Coal, and Geothermal Resources reported that the majority of Indonesia's coal reserves were located on the islands of Sumatra and Kalimantan.

Sumatra is one of the second-largest coal-producing regions in Indonesia with four potential coal mining regions: West Sumatera, Bengkulu, Central Sumatera, and South Sumatra. It has been widely reported that Sumatra has a variety of considerable coal basins, which provide coal reserves of various grades. In order to optimize the efficiency as well as utilization of this coal supply, a thorough study of the coal quality in several Sumatran coal basins is required.

The environmental condition where the coal is formatted is affected the quality of the coal deposit in each basin (Nasution and Nalendra, 2017). Geological and geochemical parameters, such as the results of preliminary and final analyses, vitrinite reflectance, and trace element levels, have a significant impact on the production and properties of coal in a mine

(Belkin, Harvey E., Susan J. Tewalt, James C. Hower, J. D. Stucker, and J. M. K. O'Keefe, 2009). This study aims to provide information about the coal quality in three different coal basins: Riau, Bengkulu, and South Sumatra. In order to investigate the coal quality between the various Sumatran coal basins, this article will focus on significant parameters such as calorific value, moisture content, and sulfur content. The characterization data is a need in order to get important information about the quality of the coal, which indirectly this information could be used to evaluate the economic value of varied coal utilization (Erwin Malaidji, E.M., Anshariah, A. and Agus Ardianto Budiman, A.A.B, 2018).

This comparative study would show significant differences in coal quality between basins. In the context of calorific value, this parameter shows the energy potential that can be produced by coal. Meanwhile, the moisture content and sulfur content affect the efficiency of use and the environmental impact of the coal combustion process. Understanding differences in these factors allows us to generate more effective techniques for utilizing coal in a way that is both environmentally and economically sustainable. As a result, this research will considerably advance our understanding of Sumatra's coal quality and is expected to be a valuable resource for geologists, the coal industry, and other key stakeholders.

METHODOLOGY

Materials and Methods

In this study, four types of coal will be tested from different coal mines in South Sumatra, Riau, and Bengkulu. In order to evaluate the quality of coal, a comparative analysis will be done in this study. The focus of the study was on three crucial parameters: calorific value, moisture content, and sulfur content. The objective of this research is to comprehend the variations in coal quality across different coal basins in Sumatra and gain a better understanding of the energy potential and environmental impact associated with the exploited coal in this region. The coal sampling process is carried out by each mine using the ASTM D197 method. The coal obtained is then reduced in particle size for analysis.

Total Moisture

Measurement of moisture content in coal, where this measurement includes free moisture and total moisture. Total moisture analysis is included in the basic analysis of coal analysis carried out in accordance with ASTM D3173: Standard Test Method for Moisture in the Analysis Sample of Coal and Coke. This moisture content analysis is the moisture value of the coal at the time after the coal is air dried at a temperature of 30-400^{o}C and the sample used was a sample that passed a 250-micrometer sieve. The coal sample is heated at a temperature of 105 ^{o}C under nitrogen gas flow or it can be compressed air. With this heating, the water in the coal will evaporate completely. Because we know that the boiling point of water is at 100 ^{o}C. The mass lost due to heating is calculated as mass percent of the initial mass used so that the value of % moisture in the analysis sample is obtained.

Total Sulfur

Total sulfur analysis belongs to the ultimate analysis of coal. Along with technological developments, this ultimate analysis has been carried out with instruments connected to computers. The procedure is quite simple by inserting a sample into the device and the results will appear on the screen of the connected computer. This sulfur analysis will be carried out by the IRS or infrared sulfur method.

Calori Value

One of the parameters that determine the quality of coal is its calorific value, which is how much energy is produced per unit mass. The calorific value of coal is measured using a device called a bomb calorimeter. A bomb calorimeter consists of 2 units combined into one device. The first unit is a combustion unit where coal is inserted into the bomb and then oxygen is injected and then the bomb is inserted into the vessel, where the coal is burned in the presence of air/oxygen supply as a burner. The second unit is the cooling/condenser unit (water handling). The calorific value of the coal sample is determined by burning the sample in an environment containing oxygen gas with a pressure of 30 atm. The heat released by combustion is equal to the calorific value of the sample. The calorific value obtained is known as Gross Calorific Value (GCV).

RESULTS AND DISCUSSION

Subsection of Results

The coal characterization analysis is discussed based on the result of total moisture content, total sulfur analysis, and caloric value. Figure 1 shows the total moisture content from the four different coal. Moisture content is one of the important parameters in determining coal quality. The total moisture content in coal can impact combustion efficiency, energy utilization, and overall coal handling (Purnama and Huda, 2019).

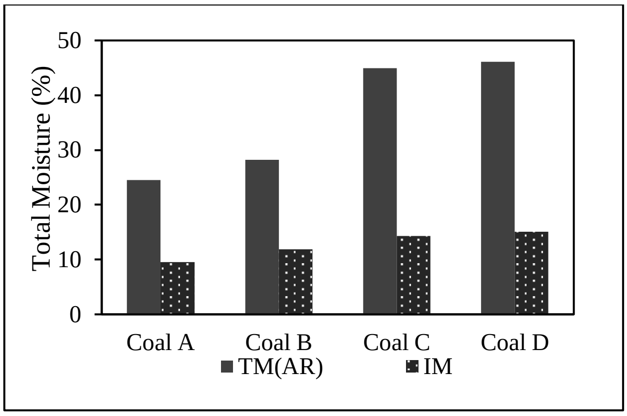

Figure 1. Total moisture content among the coal samples

The TM and IM in the figure mean total moisture and inherent moisture, respectively. Total moisture content in coal refers to the coal's overall moisture content, including the moisture bound within the coal structure (inherent moisture) and the moisture on the external surface (surface moisture). Inherent moisture is the moisture that exists within the microscopic structure of coal. It is unable to be easily removed since it is chemically attached to the coal. This moisture is formed during the coalification process when plant matter undergoes physical and chemical changes over millions of years to become coal. Different types of coal can have varied amounts of inherent moisture, which typically ranges from a few percent to several tens of percent. This total moisture content usually will be used as the standard to convert the ash received (AR) conditions for each parameter analysis. Figure 1 above explain that Coal C and D have a higher total moisture content (almost 45%) than Coal A and B (around 25-30%). While the inherent moisture for all the samples tested almost has the same percentage around 10-15%. This data describe that Coal C and Coal D have a high percentage of surface moisture contents. Surface moisture content also known as extraneous moisture, is the moisture that coats the external surface of coal particles. It can come from various sources such as rain, dew, or moisture during transportation and storage. Surface moisture is relatively easier to remove compared to inherent moisture and can be reduced through drying processes.

Moisture content in coal causes a portion of the energy to be bound in the form of water (Setiawan Rauf, Widodo, and Nawir, 2018). When coal is burned, energy is required to vaporize and remove this moisture, reducing the available energy for actual combustion. So, the higher the moisture content in coal, the lower its calorific value. Figure 2 shows the calorific value for Coal A, B, C, and D. The calorific value of coal refers to the amount of heat generated when coal is burned under optimal conditions. It is an important measure for evaluating the quality and energy potential of coal. The calorific value of coal can vary depending on the type of coal, with coal containing higher carbon content generally having a higher calorific value.

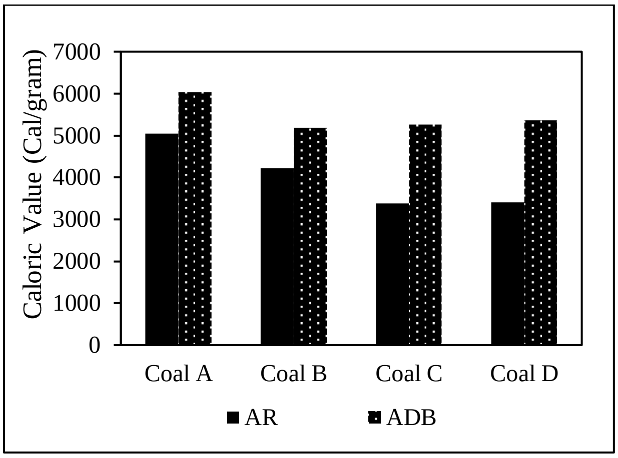

Figure 2. Caloric value among the coal samples

The calorific value in Figure 2 is expressed in the values of calorific value in AR (Air Received) and ADB (Air Dry Basis) conditions. The calorific value of coal in the AR condition refers to the calorific value of coal that has been corrected based on the total moisture content in the coal at the time of receipt or sampling. The AR condition reflects the state of coal that still contains natural moisture, including inherent moisture and adherent moisture that is bound to the coal surface. In Figure 2 the highest AR calorific value is in Coal A which is around 5000 cal/g and the lowest calorific value is around 3500 cal/g. Then, ADB calorific value has almost the same value which is around 5500-6000 cal/g. The calorific value of coal in the ADB condition refers to the calorific value of coal that has been corrected by eliminating the effect of total moisture in the coal. The ADB condition reflects the state of coal that is completely free from moisture. In the ADB condition, the calorific value of coal is calculated based only on the components of coal that produce energy when burned, namely carbon, hydrogen, sulfur, and oxygen.

In addition to the moisture content, the sulfur content in coal also plays a role in determining its calorific value. Coal with high sulfur content tends to have a lower calorific value. This is because sulfur has a relatively low calorific value and can reduce the energy potential generated during coal combustion. Total sulfur means that sulfur forms in coal are influenced by the genesis of coal (Mahapatra, 2016). The sulfur content is one of the indicators of coal quality. Knowing the sulfur content helps in evaluating and comparing the quality of different types of coal.

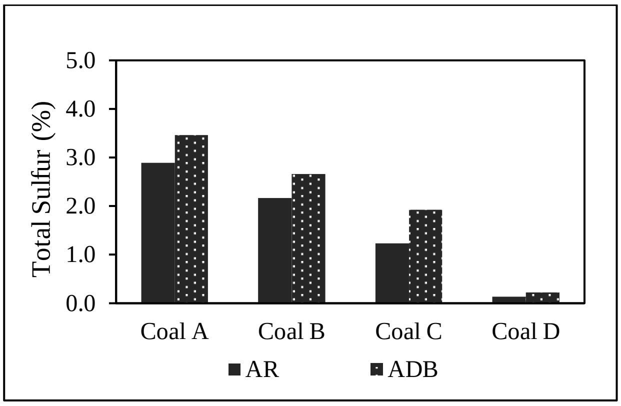

Figure 3. Total sulfur content among the coal samples

Figure 3 gives the result of the total sulfur which are contained in all coal samples also in AR and ADB conditions. Among the four samples, the total sulfur for the ADB condition is higher than the AR condition. The higher ADB sulfur content than the AR sulfur content indicates that moisture in coal has a significant impact on sulfur measurements. A higher sulfur content in the ADB condition suggests that, after eliminating the total moisture effect, the coal contains a relatively higher amount of sulfur compared to other components that produce energy during combustion. Figure 3 also shows that coal A has the highest total sulfur which is around 3.4%, and coal D has the lowest which is around 0.2%. The sulfur content in coal can be affected by various factors, including the type of coal, mining location, natural processes of pollution formation, and the methods used for processing and cleaning. These factors play a role in determining whether the sulfur content in coal is high or low.

Subsection of Discussion

Coal formation is a long-term geological process. Over millions of years, organic material from dead plants has been deposited and transformed in this process (Rustian, R., Rianto, D.J. and Rahmawati, E, 2021). Throughout the coal formation process, various factors such as temperature, pressure, time, and the types of organic material involved will influence the resulting characteristics of coal. It is important to note that the characteristics of coal can also vary between different coal deposits in different regions, depending on the geological conditions and formation processes specific to each location.

The three main characteristics of coal that discuss in this study is total moisture, calorific value, and total sulfur. The relationship between total moisture, calorific value, and total sulfur in coal provides important insights into the quality and characteristics of the coal. Firstly, total moisture in coal refers to the overall amount of moisture contained within it. This moisture content can affect the calorific value of the coal. Additionally, the sulfur content in coal also plays a significant role in determining the quality and calorific value of the coal. Sulfur in coal can originate from natural sources as well as human activities. The presence of sulfur in coal can result in the emission of sulfur dioxide (SO_2) when the coal is burned, which can contribute to air pollution and have negative impacts on the environment and human health.

Table 1 compares the three main characteristics of coal from four different samples of coal namely Coal A, B, C, and D with the characteristic data of coal from ASTM. Coal A is coal that comes from one of the basins in Riau Province, Coal B has come from one of the basins in Bengkulu, Coal C comes from one of the basins in Musi Banyuasin, South Sumatra and Coal D has come from one of the basins in Jambi Province.

Based on the table, the total moisture for Coal C and D is much higher than for Coal A and B, so the texture for Coal C and D is moisture. Coal C and D have almost the same characteristic in total moisture because of the position of the coal basin itself. The position of the coal basin for sample Coal C is near Jambi Province which is known to have a moist condition (Nasution and Nalendra, 2017). The total moisture content in a lump of coal is affected by the geology condition of the coal mine.

The higher the total moisture content, the lower the calorific content value in coal (Amriansyah and Sihombing, 2021). This calorific value from Coal C and D proved this condition. Based on their calorific value, Coal C and D belong to the low-caloric value coal. Based on the calorific value and total moisture data in Table 1 could be seen that Coal A belongs to the class of sub-bituminous coal while Coal B, C, and D belong to the class of lignite coal because have calorific values in the range of 3500-5000 cal/g. Coal with a calorific value ranging from 3500 to 5000 calories per gram is generally classified as medium to medium-high quality coal. This calorific value range reflects a relatively high energy potential when the coal is burned. Specific quality requirements for coal can vary depending on industrial needs or specific applications.

Table 1. Comparison of total moisture, total sulfur, and calorific value for the coal A, B, C, and D

Parameters	Sample				Coal Rank (Nur, et al., 2019)		
	Coal A	Coal B	Coal C	Coal D	Bituminous	Sub-Bitiminous	Lignite
Total Moisture (% AR)	24.48	28.21	44.94	46.08	10-25	20-35	25-40
Total sulfur (% ADB)	3.46	2.66	1.92	0.22	0.3-1.5	0.2-1.0	0.1-0.6
Caloric value (cal/g, AR)	5042	4222	3381	3402	5500-7000	4500-5500	3000-4500

Generally, higher calorific value coal tends to have lower sulfur and moisture content. Table 1 shows that coal A (Jambi) has the highest calorific value (5042 cal/g) among the other sample, but also has the highest total sulfur (3.46%). The same condition also occurs in Coal B and Coal C. This condition raises an interesting consideration regarding the use of this coal. A high calorific value indicates that the coal has significant energy potential. With a calorific value of 3500-5000 cal/g, this coal can provide substantial energy output when burned. This makes it an attractive option for industries that require strong and efficient energy sources. However, it is important to note that a high sulfur content also has implications that need to be taken into account. A high sulfur content can lead to significant emissions of sulfur dioxide (SO_2) when the coal is burned. SO_2 is a toxic gas that can contribute to air pollution and have negative impacts on the environment and human health. The higher sulfur in coal will have an impact on the environment and also could cause damage to the burner (Artiningsih, Widodo, and Firmansyah, 2015). Sulfur content in coal is a geochemical characteristic that refers to the conditions of the coal deposition environment and the degree of seawater influenced during the coal deposition (Pamekas, Satro Fajar; Nurdrajat; and Ghani, R.M.G, 2019). Sulfur is part of the carbonaceous minerals with its characteristic that it easily combines with the elements hydrogen and oxygen and forms acidic compounds (Widodo, Sri, Wolfgang Oschmann, Achim Bechtel, Reinhard F. Sachsenhofer, Komang Anggayana, and Wilhelm Puettman, 2010). The permissible sulfur content in coal that is accepted for the combustion process in the industry is 1%.

Furthermore, it is important to acknowledge that the use of coal as an energy source still has negative environmental impacts, including greenhouse gas emissions and air pollution. In the long term, further research and development in clean and alternative energy technologies are expected to reduce dependence on coal and transition to more sustainable and environmentally friendly energy sources. Several researchers lately were studying about of to decrease the total sulfur content, which as coal cleaning for sulfur removal (Ohtsuka, 2019), coal desulfurization by using air and water (Siswati and Festiani, 2010), coal desulfurization with the addition of plant-based oil (Syamsidar, 2011). Further research and development of cleaner and more sustainable energy technologies should be encouraged to reduce our reliance on coal and transition to a more sustainable energy future.

CONCLUSION

This study evaluated the characteristics of coal in various coal basins in Sumatra, with a specific focus on calorific value, moisture content, and sulfur content. Based on the research findings, the analyzed coal falls into the sub-bituminous and lignite categories, which generally have lower calorific values compared to other types of coal. Meanwhile, the majority of the analyzed coal samples had high sulfur content. This high sulfur content can have negative environmental and human health impacts, particularly when the coal is burned and emits sulfur dioxide (SO_2) emissions. The research findings highlight the need for serious attention to coal quality in Sumatra, particularly concerning the high sulfur content. Efforts should be made to reduce sulfur emissions and implement more efficient and environmentally friendly emission control technologies.

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