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Study of Coal Ash Content Separation in Mallawa Area using The Dense Medium Separation Method

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Abstract

Coal remains a major energy source globally, particularly for power generation and industries like iron, steel, chemicals, and cement. Indonesia's coal reserves are widespread, spanning regions such as Aceh, South Sumatra, East Kalimantan, and South Kalimantan. The Mallawa Formation in South Sulawesi also has coal, but it is of low quality due to high ash content, which lowers the calorific value and increases environmental pollution. Therefore, beneficiation is necessary to reduce ash content. The Dense Medium Separation method effectively separates coal from impurity minerals based on density. This study aims to evaluate ash reduction and separation yield across various coal fraction sizes. The coal washing process was conducted on fractions -60+80, -80+100, -100+150, and -150+200 mesh, using a perchloroethylene solution with a density of 1.6 g/ml as the separation medium. Initial coal sample analyses included proximate, calorific value, total sulfur, and mineral matter. Results showed Mallawa coal has 2.94% moisture, 40.60% volatile matter, 47.39% fixed carbon, 9.07% ash, 2.41% total sulfur, and 7053 kcal/kg calorific value, containing quartz, pyrite, calcite, and chlorite minerals. The DMS process on the -150+200 mesh fraction gave the best outcomes, with 50.39% ash elimination and 30.7% yield, making it the optimum size for ash separation in Mallawa coal.

Keywords: Coal, Ash, Dense Medium Separation, Fraction, Yield

Introduction

Coal, as one of the most important organic fuels, is formed from the biochemical, chemical, and physical decomposition of plants in an oxygen-free environment, occurring under specific pressure and temperature conditions over an extremely long period (Arifin Mubdiana et al., 2020). Coal remains a significantly utilized energy source globally, primarily due to its relative affordability. Global coal demand is dominated by electricity generation and applications in the iron, steel, chemical, and cement industries (Afin & Kiono, 2021). In Indonesia, coal reserves are widely distributed from Sumatra to Papua, with the greatest potential in Aceh, South Sumatra, East Kalimantan, and South

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Kalimantan (Irwandy Arif, 2014). Currently, most of Indonesia's electricity needs are still met by power plants that use fossil fuels, such as petroleum and natural gas. As fossil energy production declines, coal is becoming an increasingly important energy source to fulfill domestic energy requirements. Furthermore, national energy policy also encourages the increased utilization of coal as a substitute for the increasingly limited fuel oil and natural gas (Afin & Kiono, 2021).

Mallawa Formation, a coal-bearing formation in South Sulawesi, is spread across the Maros, Pangkep, Barru, Soppeng, and Bone Regencies (Anshariah et al., 2021). However, the utilization of Mallawa Formation coal is still not optimal, with one factor being the low quality of the coal. Therefore, it is necessary to improve the quality of the coal, focusing on reducing the ash content.

The presence of ash as an impurity in coal significantly reduces its quality and calorific value, leading to a decrease in combustion efficiency and an increase in environmental pollution. Ash contained in coal is an inorganic compound contained in coal since the formation process or carried during the mining process. Coal impurities consist of minerals such as quartz, pyrite, carbonate, and clay. The presence of minerals in coal appears in various forms such as grains, nodules, lenticles, and bands with particles smaller than macerals (Gao, 2009). To increase the economic value of low-quality coal, a beneficiation process is necessary before it can be utilized. Various beneficiation methods, including physical, chemical, physicochemical, and biological techniques, have been developed to reduce ash and sulfur content, Additionally, some studies have incorporated drying processes for coal with high moisture content (Groppo, 2017).

Dense Medium Separation (DMS) is a highly efficient technique for separating coal from its impurity minerals based on density differences. This process yields two separation results: the "sink" fraction, which contains coal with impurities, and the "float" fraction, which is the light or clean coal (Saputno et al., 2023). The potential benefits of DMS are quite large, but research on its application for ash separation in coal, particularly Mallawa coal, remains limited. Therefore, this research aims to evaluate the performance of DMS in separating ash from coal and determine the optimum particle size parameters to achieve maximum ash reduction while minimizing coal loss.

Research Methods

The research methodology outlines the steps and parameters employed in this study. The approach utilized is quantitative research with experimental methods. The research process involved sampling, sample preparation, initial analysis of coal samples, and coal washing.

1) Coal Sampling and Preparation

   The coal samples for this study were collected from Uludaya Village, Mallawa District, Maros Regency, South Sulawesi Province. The sampling site is situated at coordinates 4°49'24.51"S and 119°52'18.57"E, as shown in Figure 1.

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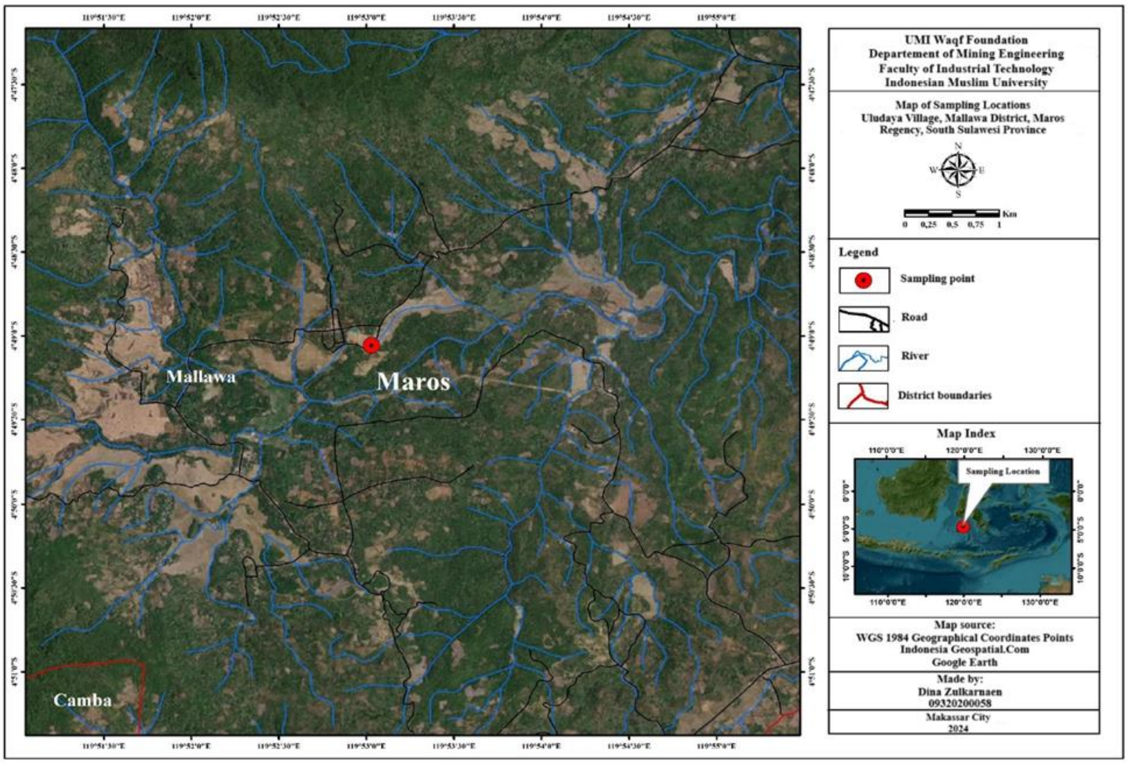

Figure 1. Map of the sampling location

Sample preparation was carried out at the Mining Materials Processing Laboratory, Department of Mining Engineering, Faculty of Industrial Technology, Universitas Muslim Indonesia. The purpose of this preparation is to reduce the sample size to prepare it for further analysis. The sample preparation process involves several stages: sample compositing, quartering, size reduction, and sieving. The objective of sample compositing is to ensure the samples taken are representative and evenly distributed. The composited coal samples were then dried by aerating them at room temperature. Comminution, or the process of reducing grain size, is carried out to meet the standard fraction of analysis that will be used. This comminution process involves using a jaw crusher, double roll crusher, and a ball mill. Quartering of samples is the division of samples into four parts, with the aim of taking original samples and reserving the rest as backup samples. Quartering also helps to homogenize the sample to be analyzed, ensuring it is representative. Finally, sieving is performed to obtain specific size fractions, including 60 + 80 mesh, -80 + 100 mesh, -100 + 150 mesh and -150 + 200 mesh.

2) Initial analysis of coal samples
3) Initial analysis of coal samples typically involves proximate analysis, calorific value, total sulfur, and mineral matter analysis. Proximate analysis is a method developed to quantify the composition of coal by heating it under specific conditions. According

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to its definition, coal proximate analysis consists of four components: moisture content, ash content (the inorganic material remaining after combustion), volatile matter (gas and water vapor that evaporates during the pyrolysis process), and fixed carbon (the non-volatile portion of coal) (Sufriadin et al., 2023). Proximate, calorific value, and total sulfur analyses were conducted at the Sucofindo Laboratory in Makassar. Mineral matter analysis, using XRD analysis, aimed to determine the mineral content in the coal samples. The XRD analysis was carried out at the Laboratory of Analysis and Mineral Processing, Department of Mining Engineering, Faculty of Engineering, Hasanuddin University.

4) Coal washing process
The coal washing process uses the Dense Medium Separation method, which is a concentration process that separates valuable minerals from their impurities based on specific gravity. This is achieved through the use of a separation medium that does not consist of water alone. Coal washing operations with DMS involve mixing the original coal into a medium with a specific gravity between that of clean coal and the heavier impurities (Alfredo, 2020). Organic liquids, such as perchloroethylene with a specific gravity of 1.6 g/ml, can be used as media in the coal washing process (Nurkhamim et al., 2023). Perchloroethylene solution is considered an ideal solution for heavy media separation due to its definite and fixed relative density (Ginting et al., 2018). The coal washing process begins by placing each sample fraction into a 250 ml glass beaker filled with perchloroethylene solution, which is then stirred for 1 minute. Next, the coal samples are allowed to stand for 60 minutes, allowing a separation between clean coal and coal with impurities. The sinking and floating parts are then separated and weighed. After the coal washing process, the sample is aerated to remove any free moisture. Following drying, the coal samples are analyzed for ash content by placing them in a furnace. The furnace is initially set to 450℃-500℃ for 60 minutes, after which the temperature is increased to 700℃-750℃ to obtain the coal ash. The ash samples are then weighed using an analytical scale. The results of this research experiment will provide the ash content of both clean coal and coal containing impurities. The percentage of ash content reduction can be calculated using the following equation (William & Sufriadin, 2024):

$$ACR\ (\%) = \frac{IAC\ (\%) - FAC\ (\%)}{IAC\ (\%)}\ x\ 100\%$$

Keterangan:
ACR = Ash content reduction (%)
IAC = Initial ash content (%)
FAC = Final ash content (%)

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This research examines not only the percentage of ash elimination, but also the yield. Yield represents the success rate of coal washing after process performance testing. The coal yield value is the ratio of the weight of clean coal to the weight of feed coal (Bramantha et al., 2022). Mathematically, it can be expressed as follows:

$$Yield = \frac{a}{b}\ x\ 100\%$$

Where:
a = clean coal weight/float (gram)
b = feed weight (gram)

Result and Discussion

1. Characterization of coal samples

XRD analysis is a method that provides information about the mineral composition of a coal sample. The analysis results of the initial coal sample analyzed by XRD are shown in Figure 2.

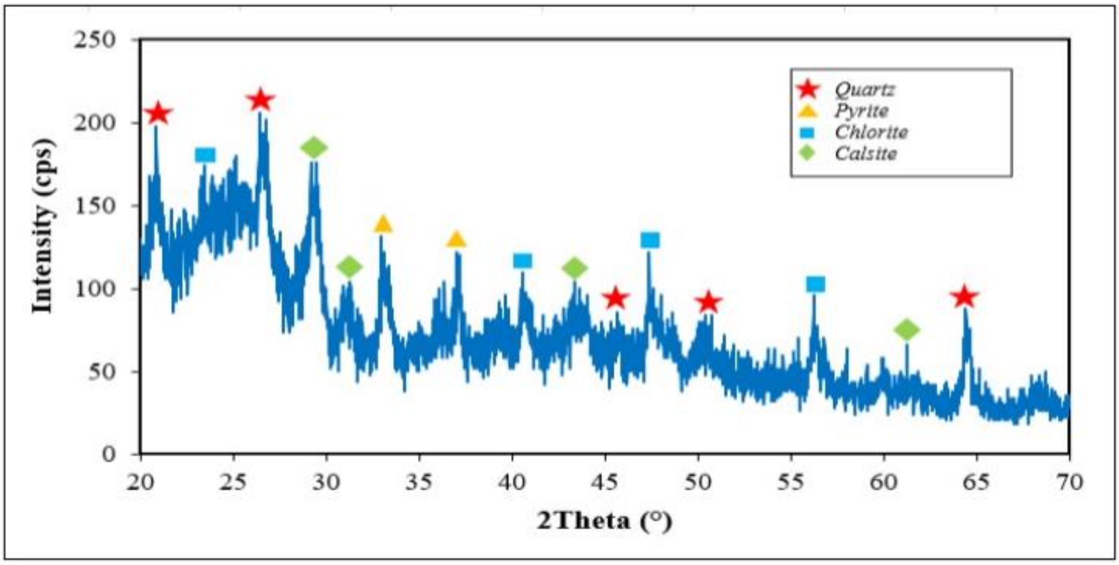

Figure 2. Diffraction pattern graph of initial coal sample

Mineral matter in coal can originate from inorganic elements within the coal-forming vegetation, known as inherent minerals. Additionally, minerals from outside the swamp or sediment may be transported into the coal deposition basin by water or wind, and are referred to as extraneous or adventitious minerals (Speight, 2012). The minerals in coal can be categorized based on their abundance as major, minor, and trace minerals. Major minerals are classified as those present at levels greater than 10% by weight, while additional minerals are present at 1-10% and trace minerals at less than 1% by weight (Renton, 1982). The major minerals found in coal are typically clay and quartz, while the common minor minerals include carbonate, sulfide, and sulfur. Pyrite is a mineral that contributes significantly to the sulfur content in coal,

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often referred to as pyritic sulfur (Taylor et al., 1998). The x-ray diffraction analysis presented in Figure 2 revealed the presence of several minerals in the analyzed coal samples, as indicated by the diffraction peaks in the diffractogram. The main minerals identified were Quartz at 41.4% and Calcite at 35%, with Pyrite at 10% and Chlorite at 14% as additional mineral. The high quartz mineral content in coal may be attributed to the Mallawa Formation, which is composed of arkose sandstones, siltstones, clays, marls, and conglomerates that are interbedded with layers or lenses of coal or limestone (Paju et al., 2006). The presence of minerals in coal can significantly impact its quality parameters, such as ash, sulfur, and calorific value, thereby limiting the use of coal.

The quality of coal samples in this study is determined based on several parameters, namely calorific value, total sulfur, and proximate analysis as shown in Table 1.

Table 1. Coal quality analysis results

Sample code	Prokximate Analysis (%)				Total Sulphur (%)	Calorific value (Cal/g)
	IM (adb)	*Ash* (adb)	*VM* (adb)	*FC* (adb)		
BBMW01	2.94	9.07	40.60	47.39	2.41	7053

Source: Report analysis analysis from PT Sucofindo (2024)

Proximate analysis of the coal samples revealed a moisture content of 2.94%, volatile matter of 40.60%, fixed carbon of 47.39%, and an ash content of 9.07%. The Mallawa coal sample exhibited a relatively high ash content of 9.07%. Consequently, it can be interpreted that the coal in the Mallawa area is unsuitable for use in the Steam Power Plant, which has an ash content standard of <7.8%, or in the cement and metal industries, which have an ash content standard of <6% (Sri Widodo, Sufriadin, 2019). The calorific value of the coal sample is 7053 kcal/kg. The calorific value of the coal sample is 7053 kcal/kg. The ASTM D 388 standard is used to determine the coal rank (ASTM, 2002):

CV (adb) → CV (btu/lb) = 7053 x 1.8 = 12695.4

$$FC\ (dmmf) = \frac{(FC - 0.15\ x\ TS)x100}{100 - (M + 1.08\ x\ A + 0.55\ x\ TS)}$$
$$= \frac{(47.39 - 0.15\ x\ 2.41)x100}{100 - (2.94 + 1.08\ x\ 9.07 + 0.55\ x\ 2.41)}$$
$$= \frac{4702}{88.58} = 53.08\%$$

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VM (dmmf) = 100 – FC (dmmf)
= 100 – 53.08%
= 46.92%

Where:
CV = calorific value (Btu = calorific value per lb)
FC = fixed carbon (%)
VM = volatile matter (%)
M = moisture (%)
A = ash (%)
TS = Total sulphur (%)

According to ASTM D 388, Mallawa coal is classified as high volatile C bituminous coal based on the determination of its coal rank. The results of this coal rank determination are shown in Figure 3.

TABLE 1 Classification of Coals by Rank[A]

Class/Group	Fixed Carbon Limits (Dry, Mineral-Matter-Free Basis), %		Volatile Matter Limits (Dry, Mineral-Matter-Free Basis), %		Gross Calorific Value Limits (Moist,[B] Mineral-Matter-Free Basis) Btu/lb		Gross Calorific Value Limits (Moist,[B] Mineral-Matter-Free Basis) Mj/kg[C]		Agglomerating Character
	Equal or Greater Than	Less Than	Greater Than	Equal or Less Than	Equal or Greater Than	Less Than	Equal or Greater Than	Less Than	
Anthracitic:									
Meta-anthracite	98	...	...	2	...	...	...	...	nonagglomerating
Anthracite	92	98	2	8	...	...	...	...	
Semianthracite[D]	86	92	8	14	...	...	...	...	
Bituminous:									
Low volatile bituminous coal	78	86	14	22	...	...	...	...	commonly agglomerating[E]
Medium volatile bituminous coal	69	78	22	31	...	...	...	...	
High volatile *A* bituminous coal	...	69	31	...	14 000[F]	...	32.557	...	
High volatile *B* bituminous coal	...	...	...	...	13 000[F]	14 000	30.232	32.557	
High volatile *C* bituminous coal	...	...	...	...	11 500	13 000	26.743	30.232	
					10 500	11 500	24.418	26.743	agglomerating
Subbituminous:									
Subbituminous *A* coal	...	...	...	...	10 500	11 500	24.418	26.743	nonagglomerating
Subbituminous *B* coal	...	...	...	...	9 500	10 500	22.09	24.418	
Subbituminous *C* coal	...	...	...	...	8 300	9 500	19.30	22.09	
Lignitic:									
Lignite *A*	...	...	...	...	6 300[G]	8 300	14.65	19.30	
Lignite *B*	...	...	...	...	...	6 300	...	14.65	

[A] This classification does not apply to certain coals, as discussed in Section 1.
[B] Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.
[C] Megajoules per kilogram. To convert British thermal units per pound to megajoules per kilogram, multiply by 0.0023255.
[D] If agglomerating, classify in low volatile group of the bituminous class.
[E] It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and that there are notable exceptions in the high volatile *C* bituminous group.
[F] Coals having 69 % or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of gross calorific value.
[G] Editorially corrected.

Figure 3. Coal rank classification according to ASTM D 388

2. Effect of Particle Size on Ash Content Reduction Using the DMS Method

The ash content separation results obtained using the Dense Medium Separation method, which accounts for particle size variations, are presented in Figure 4.

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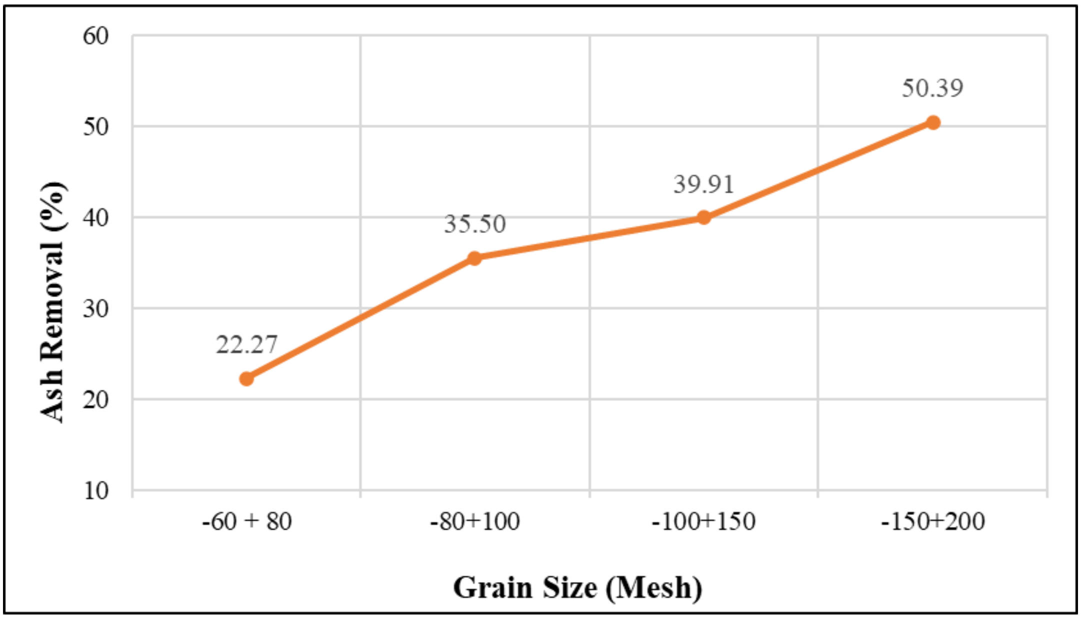

Figure 4. Graph of the effect of grain size on ash content

Tthe graph in Figure 4 demonstrates that finer fraction sizes are associated with higher ash content elimination. The best ash content elimination, at 50.39%, was achieved with the -150+200 mesh size fraction. Particle size significantly influences ash content reduction. Smaller particles have greater surface area per unit mass than larger particles, which enhances interaction between coal particles and the separation medium used (Austin & Luckie, 1984). Particle size also affects the degree of liberation of impurity minerals from coal. The finer the grain size used, the higher the degree of liberation of impurity minerals. This allows the impurity minerals more opportunities to separate in the sink layer and not join the floating coal layer, as a result, the ash content of the clean coal is reduced to a greater extent. (Gaudin, 1980).

3. Effect of Particle Size on Coal Yield
   Particle size significantly affects the coal yield. As shown in Figure 5 Based on the graph in Figure 5, the coal yield varies with particle size. At the coarse grain size of -60+80 mesh, the yield value is 33.0%. The coal yield then decreases at the finer grain size of -80+100 mesh, which is 22.9%. However, the yield slowly increases in the size fractions of -100+150 mesh (27.1%) and -150+200 mesh (30.7%), though these values are not significantly different from the coarser -60+80 mesh fraction. In general, smaller particle sizes can result in higher coal yields due to better mineral liberation. However, particles that are too fine can also lead to lower coal recovery due to difficulties in separation, such as the formation of suspensions and potential coal loss into the ash fraction. This is also one of the requirements in the DMS process

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that there should be no fine material because if the material merges with the solution, it will form a high and thick suspension (Saputno et al., 2023).

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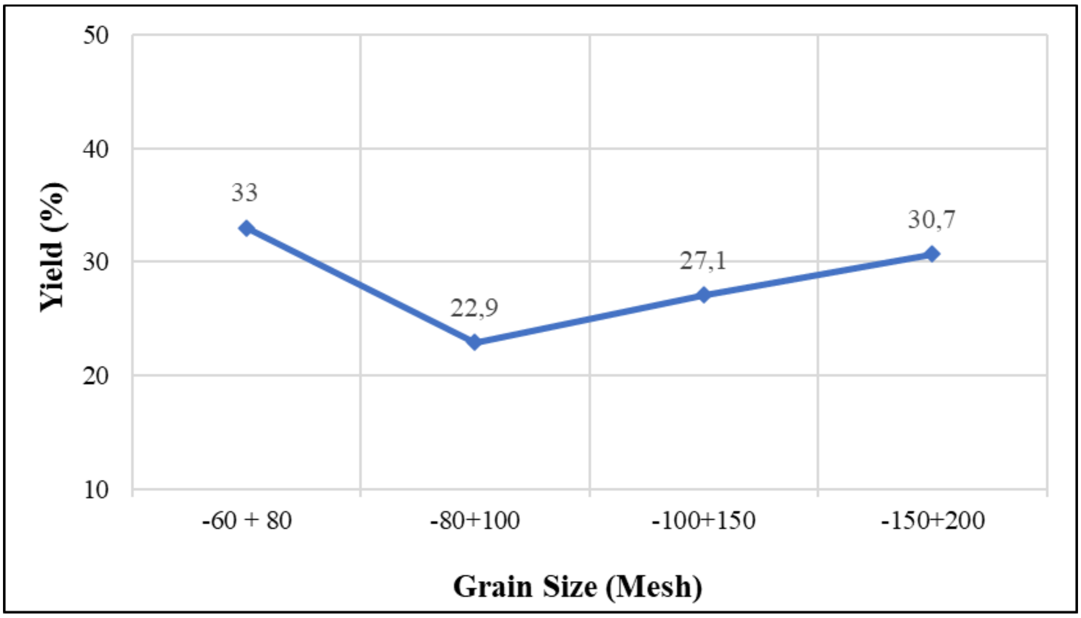

Figure 5. Graph of the effect of grain size on coal yield

Conclusion

The results of mineralogical analysis of Mallawa coal samples consist of Pyrite, Calcite, and Chlorite quartz minerals. Based on the results of proximate analysis, coal samples contain moisture content of 2.94%, volatile matter of 40.60%, fixed carbon of 47.39%, ash content of 9.07%, and total sulphur of 2.41%, Mallawa Formation coal has a calorific value of 7053 kcal/kg classified as high volatile C bituminous coal. The results of coal washing using the Dense Medium Separation (DMS) method show the highest percent ash reduction and yield value in the size fraction -150+200 mesh of 50.39% and 30.7%, respectively. This fraction can be considered as the optimum size for ash separation in Mallawa coal.

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