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Mixture composition and coal size effect on coal water mixture quality

Bazlina D. Afrah[1,*], L. Cundari[1], Ni'matul H. V. Awan[1], Illovine H. Enggar[1], E. Oktarinasari[2], M. Afrah[3]

[1]Department of Chemical Engineering, Faculty of Engineering, Universitas Sriwijaya, Indonesia
[2] Department of Mining Engineering, Faculty of Engineering,, Universitas Sriwijaya, Indonesia
[3]Faculty of Mining and Petroleum Engineering, Institute of Technology Bandung, Indonesia
*Correspondence: bazlina.afrah@ft.unsri.ac.id

Abstract

Coal usage as a primary energy source is targeted to continue to increase and replace petroleum as the main energy source. Further processing is required to achieve the standard fuel characteristics, one of which is through a process called Coal Water Mixture (CWM) by adding water and additives to coal to produce fuel with characteristics like heavy oil. This research was conducted to analyze the best composition and size of the coal for CWM processing using variations in coal composition (20 %; 30 %; 40 %; 50 %; and 60 %) and coal particle size (40, 80, and 120 mesh). The parameters studied for each CWM product are product quantity, inherent moisture, density, pH, and calorific value. The results of the initial analysis show that the CWM product with a coal composition of 50 % has characteristics that most closely resemble Heavy Fuel Oil (HFO). CWM product with a coal composition of 50 % with all three variations of coal size was then tested for its calorific value and the respective values were 3476.3153 cal/g; 4025.5551 cal/g; and 4488.4248 cal/g. The resulting product meets the physical characteristics qualifications, but to substitute HFO as fuel, it is necessary to use high quality coal, namely anthracite with a higher calorific value or upgrade the coal raw materials that will be used for the CWM processing.

Keywords: coal, coal composition, coal size, coal water mixture, heavy fuel oil

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1. INTRODUCTION

The increase of coal usage as a primary energy source is targeted to occur until the role of coal will slowly replace petroleum as the main energy source. National Energy General Plan data shows that the percentage of coal usage as an energy source in the primary energy mix in 2015 was 30 % or around 119.8 Million Tons of Oil Equivalent (MTOE). This value is expected to continue to increase to 255.9 MTOE (25.9 %) in 2050.

Indonesia's coal production volume is very large and exceeds domestic needs. Coal production in 2015 reached 461.6 million tons of coal while domestic coal demand was only 95.8 million tons. This condition causes the majority of coal produced to be allocated to export activities. The high number of Indonesian coal

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exports has recently attracted the government's attention. It is feared that Indonesia's coal reserves will run out in the near future without being used for maximum domestic needs. Therefore, the government has set a policy of limiting production to a maximum of 400 million tonnes in 2019 and is slowly reducing the amount of exports.

The level of domestic coal consumption in Indonesia is quite high and has already reached 9th place in the world ranking with 62 MTOE or 115 million tons in 2018. However, diversification of coal usage is not wide enough. A total of 98 million tons of coal from the total 138 million tons of domestic coal demand in 2019 was used for electricity generation (Minister of Energy and Mineral Resources of RI, 2021). Utilization of coal as fuel is considered more difficult compared to petroleum, which is why coal usage is still not widespread.

Expanding the diversification of coal energy utilization to increase domestic coal consumption can be done by converting coal into a product which characteristics are similar to petroleum. This conversion can be done by Coal Water Mixture (CWM) technology. These changes in the product characteristics will make the coal product can be used to substitute the utilization of HFO even under certain conditions without having to modify the combustion tank.

CWM is a coal processing technology designed as a solution to coal transportation problems. This technology was first designed in Japan as fuel oil (BBM) in power plants. The oil crisis that occurred from 1973 to 1978 forced engineers to look for alternatives to fuel oil that had long been used because oil prices were increasingly high. Therefore, researchers then focused on efforts to simplify the handling of solid fuels such as coal. CWM with advantages such as the production of high solids concentration, saving from transport, storage and dewatering costs are regarded as an alternative to fuel oil (Atesok et.al., 2002). CWM can also be stored without the danger of coal-dust explosion, pumped, transported in pipelines and combusted like fuel oil in an environmentally benign manner (Shin et. al., 2006). CWM product that have been prepared from low-rank coals have shown excellent (Xu et.al.,2008). Several research works about Coal-water Mixture have been done concerning the production and its develpoment worldwide in several different governmental, industrial and academic facilities (Nunes, 2020).

CWM is a fuel produced from the mixing process of coal and water using additives to form a thick suspension that is stable during storage, transportation and combustion. Each of the three raw material have different roles and must be combined in appropriate amounts to get a mixture that is stable, economical and can be used as a fuel substitute. Additives are added to the coal and water mixture to keep the coal well dispersed. Additives are added because of the differences in properties between coal and water, making coal tend to settle when mixed with water. The materials used as additives are usually surfactant compounds which are able to influence surface tension. To stabilize CWM, additives are used in the form of Carbon Methyl Cellulose (CMC) and Alkyl Benzene Sulfonic (ABS) is used as a dispensing agent. (Juhantoro et al., 2012).

To be able to replace heavy oil, CWM products must have characteristics such as viscosity and density that resemble HFO. Based on several studies about CWM application as an alternative of heavy oil, no special conditions are required for CWM storage or transport since this fuel emits less sulfur and nitrogen oxides so loading and unloading costs are virtually nonexistent (Burdukov et.al., 2002). Apart from that, the calorific value and inherent moisture also need to be considered to ensure that the product remains suitable for utilization as fuel. Juhantoro et al. (2012) in their research varied the temperature in the CWM production process using a mixture ratio of coal and water of 40 %: 60 %. This research aims to determine the impact of temperature changes in the CWM manufacturing process on the fuel produced in terms of 5 aspects, namely density, viscosity, calorific value, inherent moisture (IM) and residual carbon. In this study, the temperature was varied at 15 ^oC, 50 ^oC, 90 ^oC, 100 ^oC and 150 ^oC. The results obtained show that the CWM product which corresponds to the characteristics of heavy oil is the product from a process that use a temperature of 50 ^oC (Juhantoro et al., 2012).

Additionally, another study by Gürses et al. (2006) showed that viscosity will increase along with the increasing coal concentration in a mixture of coal and water. This research by Gürses et al. aims to determine the impact of stirring speed variation combined with several variables including coal weight percentage, surfactant weight, moles of electrolyte, temperature and pH on CWM viscosity. From this research it can be concluded that increasing the amount of surfactant and temperature causes a decrease in viscosity while increasing the weight percent of coal causes an increase in the viscosity value. The viscosity value with increasing moles of electrolyte and pH is unstable so it does not provide any conclusions.

Coal particle size can also greatly influences the stability of CWM. Accordance with Stokes' Law the larger the size of the coal particles, the coal deposition in water will increase. Based on several studies that have been carried out, the optimum coal particle size is 80 % passing a 200 mesh sieve and 20 % of them are no larger than 120 mesh (Umar, 2010).

This research focuses on analyzing the influence of variations in coal and water composition and coal size on the CWM process using a range of 20 %, 30 %, 40 %, 50 %, and 60 % for the coal mass composition of and 40, 80, and 120 mesh for the coal sizes variations. Through this research, the best composition and size of coal that is most suitable for the CWM production process will be obtained based on the similarity of viscosity and density with heavy oil as well as the calorific value and water content inherent in the CWM product.

2. MATERIALS AND METHODS

This research is located at the Separation and Purification Engineering Laboratory, Faculty of Engineering, Sriwijaya University. This research was carried out from 3 December 2020 to 6 September 2021. The research stages carried out included the following steps:

2.1. Raw Material Preparation

The raw materials used in this research were Sub-Bituminous class coal from PT Bukit Asam Persero, Aquadest, Carboxy Methyl Cellulose (CMC), and Alkyl Benzene Sulfonate (ABS) (0.07 % CMC and 0.01 % ABS). The coal goes through a crushing stage using a porcelain cup and mortar to obtain coal powder with varying sizes of 40, 80 and 120 mesh.

2.2. Coal Water Mixture (CWM) Production

The coal and water mixing process is carried out with a coal ratio in the mixture of 20 %, 30 %, 40 %, 50 % and 60 % with additives of 0.07 % ABS and 0.01 % CMC. Mixing was carried out in a series of dewatering mixing equipment with a stirring speed of 900 rpm and a temperature of 50 ^oC for 60 minutes. The series of dewatering mixing equipment used consists of a magnetic stirrer, beaker and thermometer (to monitor the process temperature during stirring).

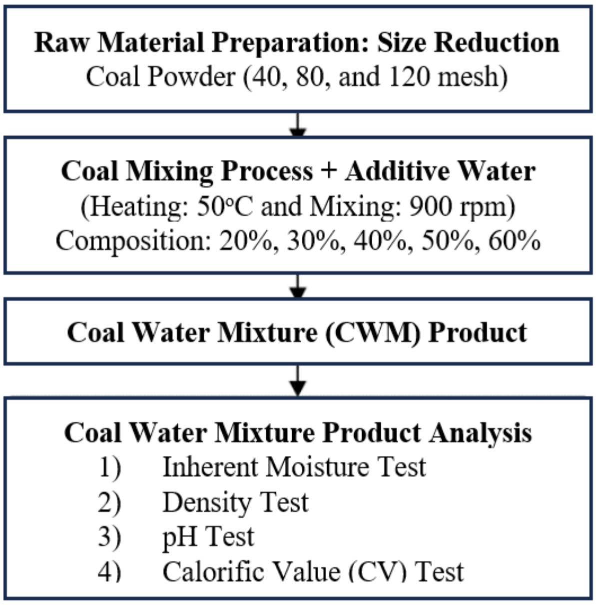

Figure 1. Coal Water Mixture Process

2.3. Product Analysis

CWM product analysis is carried out in the Process Engineering Laboratory, Chemical Industry Products. The analysis carried out includes analysis of pH, density and inherent moisture. Calorific Value (CV) testing was carried out at the South Sumatra Mining Service using a Parr 6400 Isoperibol Calorimeter with ASTM D 2013/2013M/12 standards.

3. RESULTS AND DISCUSSION

3.1. Size particle and Coal Composition Effect on the Amount of Coal Water Mixture (CWM) Produced

The efficiency of the CWM manufacturing process is shown by the number of products produced, where the higher the number of products produced, the more efficient the CWM manufacturing process is because the losses that occur during the process are reduced. Figure 2 shows the influence of mass percent and coal size on the amount of CWM product.

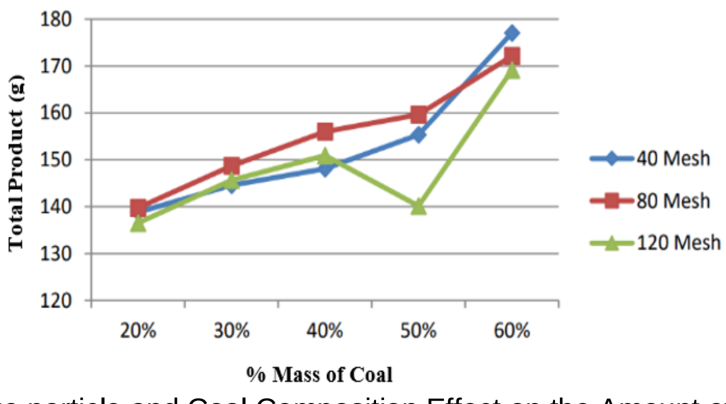

Figure 2. Size particle and Coal Composition Effect on the Amount of Coal Water Mixture (CWM) Produced

Based on the research data shown in Figure 2, by using a mixture of 200 grams of coal and water (initial mass), the highest number of products was obtained in the sample with a mixture of 40 mesh 60 % coal size, namely 177.0672 grams, while the number of products at least 136.5152 grams was obtained in samples with a mixture of 120 mesh 20 % coal size. These data show that the amount of product produced will increase as the mass composition of coal increases and the water composition in the raw material mixture decreases.

Stirring was carried out at a temperature of 50 ^{o}C for 60 minutes to allow evaporation of water which caused a reduction in the mass of the CWM product. The heating temperature during the stirring process causes the release of water molecules from the coal pores. When the temperature increases, the moisture in the coal will begin to evaporate along with increased heat release (Fan et al., 2019).

The number of products produced from the three coal particle sizes with a coal mass composition of 60 % increases as the particle size increases. Research by Faruq et al (2019) shows that increasing particle size will reduce the water content of the resulting product (Faruq, 2019).The decrease in CWM product mass for mixtures with higher water composition will also be greater. Increasing the coal composition in the mixture will cause the water composition to decrease so that the decrease in the mass of the CWM product becomes smaller with the decrease in the amount of water that can be evaporated.

3.2. Size particle and Coal Composition Effect on the Inherent Moisture (IM) of Coal Water Mixture (CWM) Produced

The water content in CWM greatly determines the quality of CWM products. The standard CWM water content is ±42 % (Daulay, 2017). The research data obtained shows that the highest IM value, namely 80.99 %, was obtained in samples with a coal size of 40 mesh and a coal content of 20 %. The lowest IM value was obtained in a sample with a coal size of 120 mesh and a coal content of 50 %, namely 23.65 %.

The overall IM value for each coal size sample of 40, 80, and 120 mesh decreased as the mass percent of the coal composition used increased. The higher the coal composition in the mixture, the amount of water used as raw material for making CWM will decrease so that the amount of water in the final CWM product and its IM value also decreases.

Coal particle size also influences the IM value of CWM products. The particle size and water content values are inversely proportional to each other. The larger the particle size, the lower the water content (Faruq, 2019). The water content will increase as the particle size decreases due to the lower absorption capacity of large particles (Priyanto & Sudarno, 2018). The surface area of large particles is small so their absorption capacity is small (Ningsih et al., 2020).

Research data for samples with coal content of 30 % and 40 % shows a correlation between coal particle size and IM which is in accordance with existing theory where IM increases as the coal size becomes smaller. However, in samples with coal content of 20 % and 60 %, the IM content actually decreased as the coal size became smaller. Meanwhile, in samples with 50 % coal content, the water content in samples with a size of 80 mesh is greater than samples of 40 mesh and 120 mesh. This phenomenon can occur due to technical errors in temperature control during the CWM manufacturing process. The higher the temperature during the CWM manufacturing process, the IM value of CWM will tend to decrease (Juhantoro et al., 2012). This is caused by the evaporation of water during the CWM manufacturing process, the amount of which will be higher as the process temperature increases.

The higher the IM value indicates the more water contained in the CWM so the calorific value decreases. Therefore, the expected IM value is as low as possible. Thus, the results of this research show that regarding the IM value, it is better if the coal composition in the mixture is greater, whereas regarding the particle size variable, strong conclusions cannot be drawn. However, based on the literature, it is better if the particle size is larger.

Apart from coming from the distilled water in the mixture, the water content in CWM also comes from the water content within the coal. This is what causes the IM value in CWM to be greater than the distilled water composition before stirring. Therefore, it is better if the quality of the coal used is high grade coal so that the water content is lower.

3.3. Size particle and Coal Composition Effect on the Density of Coal Water Mixture (CWM) Produced

The density of a mixture is generally influenced by the density of the material from which it is made so that the density of CWM will be influenced by the density of water, coal and additives. The density of CWM tends to decrease as the process temperature increases. This is caused by increasingly massive evaporation as the process temperature increases (Juhantoro et al., 2012). By assuming that the dominant component to evaporate is water, it can be concluded that the density of coal is lower than water, because the density of CWM decreases as the mass of water decreases.

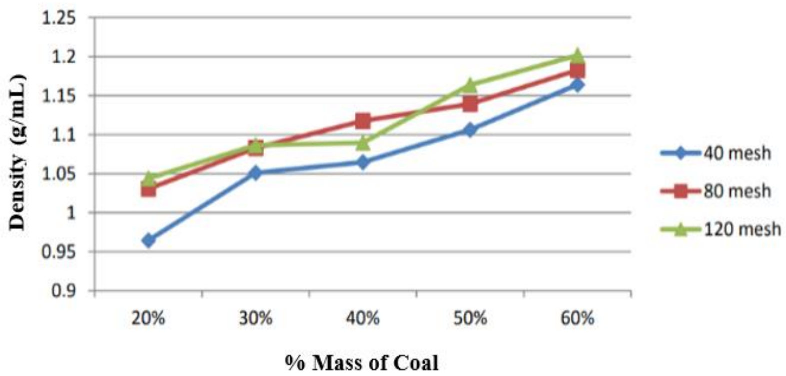

Figure 3. Size particle and Coal Composition Effect on the Density of Coal Water Mixture (CWM) Produced

The influence of mass percent coal composition and coal size on the density of CWM is shown in Figure 3. Based on the data obtained, the density of CWM tends to increase as the amount of coal increases and the amount of water in the CWM decreases. The contradiction between research data and existing theory means that the density of coal can be concluded to be higher than the density of water. This contradiction can be caused by the different types of coal used in making CWM, where different types of coal have different levels of water, carbon and other constituent substances so that their densities are different.

The density of CWM is also influenced by the size of the coal powder. The density will increase as the particle size becomes smaller, because smaller particles will produce stronger particle bonds (Priyanto & Sudarno, 2018). The research data shown in Figure 3 is in accordance with this statement, however there is a slight difference in the sample with a coal composition of 40 % where the 120 mesh sample has a lower density than the 80 mesh sample. This can be caused by errors in temperature handling so that the evaporated water content in the two samples is different and there is instability in the density data.

Based on the ISO-3675 standard, the density of Heavy Fuel Oil (HFO) is 1142.4 kg/cm^3 or 1.1424 g/mL. In this research, the three samples are all close to this standard. CWM with the coal particle size of 80 mesh and composition of 50 % samples has a density value of 1.13908 g/mL, meanwhile sample 120 mesh - 50 % has a value of 1.16338 g/mL and 40 mesh - 60 % sample with a value of 1.16385 g/mL. The value of the density of CWM which is close to the density of HFO causes CWM to be concluded as worthy of replacing HFO.

3.4. Size particle and Coal Composition Effect on the pH Value of Coal Water Mixture (CWM) Produced

pH value shows the acidity level of a substance, where the lower the pH value, the more acidic the substance is and the higher the pH value, the more alkaline the substance. The effect of the size and amount of coal in the mixture on the pH of the CWM product is shown in Figure 4.

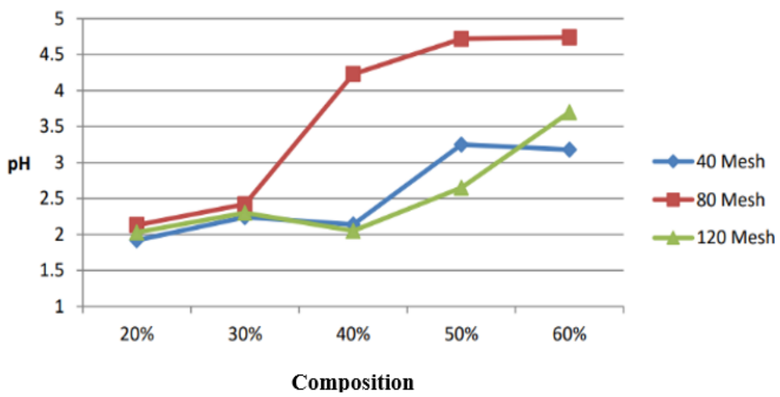

Figure 4. Size particle and Coal Composition Effect on the pH Value of Coal Water Mixture (CWM) Produced

Based on Figure 4, it can be seen that the highest pH value, namely 4.74, was obtained in a sample with a coal size of 80 mesh 60 %, while the lowest value, namely 1.92, was obtained in a sample with a coal size of 40 mesh 20 %. All CWM samples produced had a pH value of less than 7, so it can be concluded that the CWM product resulting from mixing coal, water and additives is acidic.

The pH value of CWM products tends to increase along with increasing coal composition in the mixture. Assuming that the pH of distilled water is neutral, then what might cause this increase is the presence of CMC and ABS additives which change the solution to become acidic. Samsudin et al. (2020) research shows that the total sulfuric in sub-bituminous coal samples is 0.42-0.58 % (Salmi et al., 2020). Higher pH value of coal will increase the pH of the solution as the coal composition increases.

At the same composition value, the highest pH value was obtained in a sample with a coal size of 80 mesh. The lowest values for compositions of 20 %, 30 % and 60 % were obtained for samples with a coal size of 40 mesh, while for compositions of 40 % and 50 % were obtained for samples with a coal size of 60 mesh.

According to ISO 8217 concerning Fuel Standard for Marine, the pH value of oil to be used as Marine Fuel Oil (MFO) is more than 2.5. This is because solutions that are too acidic have stronger corrosive properties, so they can cause damage to combustion engine components or distribution pipes. In this study, as many as 7 samples had a pH of more than 2.5 so they were suitable as a substitute for MFO, including samples of 40 mesh 50 %, 40 mesh 60 %, 80 mesh 40 %, 80 mesh 50 %, 80 mesh 60 %, 120 mesh 50 % and 120 mesh 60 %.

3.5. Size particle and Coal Composition Effect on the Calorific Value of Coal Water Mixture (CWM) Produced

The effect of varying coal particle size on the coal : water composition of 50 % is shown in Figure 5. The 50 % composition was chosen because this variation has the best characteristics and is in accordance with CWM standards based on four previous tests.

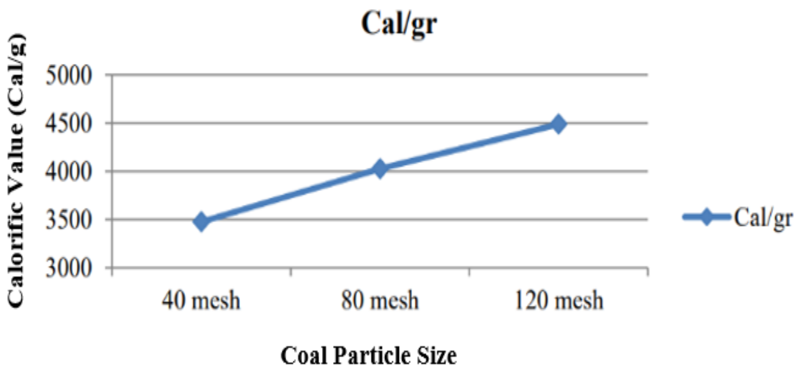

Figure 5. Coal Size particle in Sample with Coal Composition of 50 % Effect on the Calorific Value of Coal Water Mixture (CWM) Produced

Figure 5 shows that the smaller the coal particle size, the calorific value of the CWM produced also increases. The higher the calorific value of the fuel, the greater the heat the fuel can produce. Thus, of the three samples tested, the sample with a coal particle size of 120 mesh had the best fuel quality when viewed from its calorific value, namely 4488.4248 cal/g or 18,617.9861 KJ/Kg.

Based on Heavy Fuel Oil (Oil) standards, the lower calorific value of HFO is 40,200 KJ/Kg. When compared with these standards, the calorific value obtained is still too low. The coal used as raw material in this research is sub-bituminous coal with a calorific value range of 3056-4611 cal/g or 12,794.8608-19,305.3348 KJ/Kg (Tanjung, 2020). The addition of water in the CWM manufacturing procedure causes a decrease in the calorific value of coal with an estimated decrease of around 1000 KJ/kg. To obtain CWM with a high calorific value in accordance with HFO standards, the raw material is required in the form of Anthracite class coal which has a calorific value of 7,222-7,778 cal/g or 30,237.0696-32,564.9304 (Tanjung, 2020). By using anthracite coal, even though the calorific value has decreased after processing, the calorific value of the CWM product is still close to the HFO standard.

Upgrading coal that will be used as raw material can also be done using the Upgrading Brown Coal (UBC) method or using oil as a mixture to produce Coal Oil Mixture (COM). The quality of Indonesian coal is dominated by low and moderate calorie coal which is classified as brown coal with a percentage of 28.94 % and 61.81 % (Rezakola et al., 2016). The UBC process can increase the use value of brown coal so that domestic energy needs for coal are met and export prices also increase (Bazlina Dawami Afrah et al., 2014). UBC products can reduce feed consumption by 50 % compared to brown coal (Bazlina Dawami Afrah et al., 2017). Research by Afrah et al. (2019) shows that the UBC process is proven to reduce water content by up to

1.8 % and the resulting product has the highest calorific value of 7,552.22 cal/g (B. D. Afrah et al., 2019).

4. CONCLUSION

Based on the research activities that have been carried out, it can be concluded that the composition of coal and water in the mixture and the size of the coal particles also influence the characteristics and quality of the CWM product produced. Increasing the amount of coal in the mixture causes an increase in the amount of product and pH of the CWM product as well as a decrease in the inherent moisture and density of CWM. The smaller the coal particle size causes the density and heating value of CWM to increase. Judging from several existing indicators, CWM has the potential to replace HFO. The three samples closest to the HFO density standard are the 80 mesh 50% sample with a value of 1.13908 g/mL, the 120 mesh 50 % sample with a value of 1.16338 g/mL and the 40 mesh 60 % sample with a value of 1.16385 g/mL . Meanwhile, 7 samples had a pH of more than 2.5 so they were suitable as a replacement for MFO, including samples of 40 mesh 50 %, 40 mesh 60 %, 80 mesh 40 %, 80 mesh 50 %, 80 mesh 60 %, 120 mesh 50 % and 120 mesh 60 %. With density and pH characteristics that are close to oil, CWM meets the physical characteristic standards for transportation, but the calorific value of the CWM produced is not yet able to meet HFO standards, so further research is needed by changing the raw material to anthracite coal and upgrading the coal that will be used. as raw material.

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