Characteristics of Briquette as an Alternative Fuel Made of Mixed-Biomass Waste (Dairy Sludge and Coconut Shell)

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ABSTRACT
Coal is used mainly in boiler units as a heat energy generator. The non-renewable nature of coal encourages creating alternative fuels, such as briquettes. The abundance of organic material in dairy sludge has potentially becomes briquettes. To improve the quality of the briquettes, it is necessary to add other biomass with high caloric value, such as coal and coconut shell. Dairy sludge and coconut shell will undergo pyrolysis to produce charcoal later mixed with the coal. The formulation was determined using linear programming, with the decision variables consisting of coal (X1), dairy sludge charcoal (X2), coconut shell charcoal (X3), and binder (X4). The purpose of linear programming is to maximize the heating value of the briquettes and obtain proximate characteristics that suit Indonesian National Standard (SNI 01-6235-2000) for wood charcoal briquettes. The charcoal yield from pyrolysis was 44.35% for dairy sludge and 27.8% for coconut shell charcoal. The optimal briquette formulation was 10% coal, 10% dairy sludge charcoal, 75% coconut shell charcoal, and 5% adhesive. The calorific value obtained reached 9247.41 cal/gram. However, the ash content did not meet the SNI 01-6235-2000.

Keywords: *Briquettes, Pyrolysis, Proximate Characteristics, Calorific Value, Linear Programming*

1. INTRODUCTION

One of the most critical aspects of industrial activity is energy sources. Large-scale industries use energy in coal, oil, and natural gas [1]. PT XYZ, a milk processing company in Indonesia, is one of the industries that use coal as a fuel source. In PT XYZ, a series of production activities require energy in the form of heat. Coal, used as a fuel in the boiler engine, produces steam. Coal plays a significant role in PT XYZ's industrial activities. However, coal is a nonrenewable energy source that contributes to climate change, emits greenhouse gases, and eventually runs out [2]. As a result, alternative energy sources that are both sustainable and environmentally friendly are required, such as biomass.

Biomass is a renewable energy source with a lot of potential in Indonesia [3]. Biomass is defined as a material or biological material derived from animal and plant remains that has the potential to be used as a fuel because it can produce heat and is classified as renewable energy [1]. PT XYZ produces 100 tons of slurry (liquid mud) per day, with 4 tons of dairy sludge remaining after pressing. Approximately 6-10 liters of wastewater are produced [4].

Due to the high production of biomass waste, PT XYZ has decided to turn dairy sludge into something useful. The abundance of organic material in dairy sludge can be used as a potential heat and power. However, due to the low caloric value, other biomass is required to increase the caloric value of dairy sludge.

Coconut shell charcoal has a calorific value of 4812.75 cal/gram, 17.89 percent cellulose, 25.82 percent lignin, 56.29 percent hemicellulose, and other ingredients make up the coconut shell [5]. Combining waste as fuels is common to increase the value and reduce coal consumption [6,7].

Briquette is a charcoal made from biological waste by compressing the biomass into a more regular shape. A mathematical formulation method, namely linear programming, is used to determine the composition of the briquette, including coal, dairy sludge, and coconut shell. The goal of linear programming is to find several alternative combinations of solutions and choose the optimum mixture [8]. As a result, linear programming was used to determine the ingredient ratio to maximize the heating value by SNI 01-6235-2000.

The addition of coal is intended to improve the briquettes' quality. The briquettes will be scaled up to an industrial scale if possible. This research compares the feasibility, proximate characteristics, and calorific value of mixed biomass waste.

2. MATERIALS AND METHODS

2.1. Materials and Equipment

Dairy sludge, coconut shell, coal, and tapioca flour were used in this experiment. PT XYZ provides the dairy sludge and coal. The coconut shells were brought from the Tanjung market in Mojokerto, East Java. Avia Stores in Malang, East Java, provided the tapioca flour. The briquette-making equipment and testing equipment were used in this study. A hammer, grinder, scale, and pyrolysis unit made the formula. 60 mesh and 100 mesh sieves, briquette molds with presses, pans, and stoves are among the briquette-making equipment used. Analytical balances, crucibles, cup clamps, ovens, desiccators, muffle furnaces, and bomb calorimeters are the testing tools used.

2.2. Experimental set-up

Research activities include preparing materials ranging from coal, making dairy sludge charcoal, making coconut shell charcoal, making adhesives, to briquette. Coal preparation includes:

1. Reducing the size of coal by using a hammer
2. Dry by drying to a moisture content of ~10%, for 5 days
3. Weighed as much as 600 grams
4. Smoothed using a grinder
5. Sieve with sieves of 60 mesh and 100 mesh
6. Measured proximate value and calorific value of coal 60 mesh
7. Coal powder obtained (100 mesh)

Dairy sludge charcoal production includes:

1. Dairy sludge is dried in the sun to a moisture content of 10%, for 7 days
2. Weighed as much as 2000 grams
3. The pyrolysis process is carried out at a temperature of 600°C for 2 hours
4. Smoothed using a grinder
5. Sieve with sieves of 60 mesh and 100 mesh
6. Measured proximate value and calorific value of 60 mesh of dairy sludge charcoal
7. Dairy sludge charcoal (100 mesh) is obtained

The production of coconut shell charcoal includes:

1. Coconut shell cleaned
2. Reducing the size of the coconut shell by using a hammer
3. Dry in the sun to a moisture content of 10%, for 7 days
4. Weighed as much as 2000 grams
5. The pyrolysis process is carried out at a temperature of 600°C for 2 hours
6. Smoothed using a grinder
7. Sieve with sieves of 60 mesh and 100 mesh
8. Measured the proximate value and calorific value of 60 mesh coconut shell charcoal
9. Obtained coconut shell charcoal (100 mesh)

The manufacture of binder solutions includes:

1. Tapioca starch is put in a saucepan and added water in a ratio of 1:10
2. Boil until the solution is homogeneous and thickens
3. Obtained adhesive solution

The last stage is making briquettes. Briquetting is done by mixing the four materials according to the formulation obtained from linear programming results.

2.3. Analysis

The determination of three elements, namely decision variables, objective functions, and constraint functions, is required to formulate linear programming. POM-QM version 4 for Windows will be used to process the data. The data processing produces an optimal formulation for each briquette constituent material or the constants of the predetermined decision variables as an output (X1, X2, X3, X4). The recipe will be used as a proportion in the production of briquettes, which will then be evaluated for proximate and calorific value.

3. RESULTS AND DISCUSSION

3.1. Proximate Characteristics and Calorific Value of Raw Materials

Table 1. Shows the proximate value and calorific value of the coal produced, identical to the type of bitumen used in Geng et al. study's (2016) [9].

Table 1 Proximate Characteristics and Calorific Value of Coal

Parameter	Analysis result	Geng *et al*. (2016)
Water content (%)	8	5.19
Ash (%)	5.5	4.78
Vollatile matter (%)	41	31.87
Carbon (%)	45.5	58.16
Calor Value (kal/gram)	5489.27	6182

Table 2. Proximate Characteristics and Calorific Value of Dairy Sludge Charcoal

Parameter	Analysis result	Kwapinska dan Leahy (2017)
Water content (%)	2.72	1.75
Ash (%)	69.5	69.68
Vollatile matter (%)	9.28	4.29
Carbon (%)	18.5	26.03
Calor Value (kal/gram)	3530.16	2245.15

Table 2 shows the characteristics of dairy charcoal, which is in line with Kwapinska and Leahy's (2017) research [10]. The notable difference is only the caloric value.

Table 3. Proximate Characteristics and Calorific Value of Coconut Charcoal

Parameter	Analysis result	Rout *et al*. (2016)
Water content (%)	6.53	2.73
Ash (%)	13	7.04
Vollatile matter (%)	0,47	18.93
Carbon (%)	80	71.3
Calor Value (kal/gram)	7025.66	5655.87

Table 3 shows the characteristic of coconut charcoal compared to Rout et al.'s (2016) [5]. The significant difference was the volatile matter and caloric value. This may be due to the difference in coconut species and age.

Table 4. Characteristics of Proximate and Calorific Value of Adhesive Solution

Parameter	Value
Water content (%)	89.19
Ash (%)	0.47
Vollatile matter (%)	9.9
Carbon (%)	0.44
Calor Value (kal/gram)	661.19

The adhesive solution used in making briquettes is a mixture of tapioca starch and water. The analysis results in Table 4 cannot be compared with other literature because there is no research related to the proximate characteristics and calorific value of tapioca adhesives. However, tapioca flour has a moisture content of 9.84% and an ash content of 0.36% [12]. Therefore, if tapioca flour is added to water with a concentration of 1:10, it is likely to increase the water content by ten times, which is about 89.19%. In addition, the ash content of the analysis results is not much different from the ash content of tapioca flour.

3.2. Linear Programming Formulation

a. Determination of Objective Function

The mathematical model represents the function of the decision variable or the goal to be optimized (maximized) [11]. The calorific value was chosen as the objective function because the calorific value shows the quality or main indicator in determining whether or not the fuel is beneficial [13]. The calorific value of each decision variable will affect the maximum heat value for the briquettes. The caloric value of the materials used in this study is shown in Table 5.

Zmaks = 5489.27 *X1* + 3530.16 *X2* + 7025.66 *X3* + 661.19 *X4* ……………………………(1)

Table 5. The caloric value of the materials

Material	Caloric value (kal/g)
Coal (X_1)	5489.27
Dairy Sludge Charcoal (X_2)	3530.16
Coconut charcoal (X_3)	7025.66
Binder (starch + water) (X_4)	661.19

b. Determination of Constraint Function

Table 6 shows the constraint function used in this study.

Table 6. Constraint Function [14]

Material	Moisture (%)	Ash (%)	Volatile matter (%)	Price (IDR/g)	Caloric Value (kal/g)
Coal (X_1)	8	5.5	41	1.2	5489.27
Dairy Sludge Charcoal (X_2)	2.72	69.5	9.28	2.06	3530.16
Coconut charcoal (X_3)	6.53	13	0.47	1.45	7025.66
Binder (starch + water) (X_4)	89.19	0.47	9.9	10	661,19
Limit	**$\leq 8^a$**	**$\leq 8^a$**	**$\leq 15^a$**	**$\leq 2{,}5^b$**	**$\geq 5000^a$**

The following is a mathematical model of the constraint function based on Table 6:

- Moisture :
  $8 X_1 + 2{,}72 X_2 + 6{,}53 X_3 + 89{,}19 X_4 \leq 8$ .... (2)
- Ash :
  $5{,}5 X_1 + 69{,}5 X2 + 13 X_3 + 0{,}47 X_4 \leq 8$............................... ..(3)
- Vollatile matter :
  $41 X_1 + 9{,}28 X_2 + 0{,}47 X_3 + 9{,}9 X_4 \leq 15$ .... (4)
- Price :
  $1{,}2 X_1 + 2{,}06 X_2 + 1{,}45 X_3 + 10 X_4 \leq 2{,}5$ .... (5)
- Caloric value :
  $5489{,}27 X_1 + 3530{,}16 X_2 + 7025{,}66 X_3 + 661{,}19 X_4 \geq 5000$.....(6)
- Coal ratio :
  $0{,}1 \leq X_1 \leq 0{,}4$ ....(7)
- *Dairy Sludge* Charcoal Ratio :
  $X_2 \geq 0{,}1$ ....(8)
- Coconut charcoal ratio :
  $X_3 \geq 0{,}45$ ....(9)
- Binder :
  $0{,}05 \leq X_4 \leq 0{,}1$ ....(10)
- Briquette composition :
  $X_1 + X_2 + X_3 + X_4 = 1$ .... (11)
- Non negativity condition :
  $X_1, X_2, X_3, X_4 \geq 0$............................... ....(12)

This study has eleven constraints, including water content, ash content, volatile matter, cost, calorific value, coal ratio, dairy sludge charcoal ratio, coconut shell charcoal ratio, adhesive ratio, and briquettes (100%), and non-negativity conditions. The maximum water content value is 8%, ash content is 8%, the volatile matter is 15%, and calorific value is 5000 cal/gram referring to SNI 01-6235-2000 regarding wood charcoal briquettes [14]. The cost of IDR. 2.5/gram is used as a limit in this study because the price of domestic charcoal briquettes, especially in Indonesia, is around IDR. 2500/kg [15]. The minimum limit of coal ratio was 10% to reduce coal as a fossil fuel. The maximum limit was 40% so that no more than 50% of its content is in briquettes. The minimum ratio of dairy sludge charcoal is 10%, meaning that the use of dairy sludge as biomass is expected to be more dominant when compared to coal.

Similarly, coconut shell charcoal to biomass is at least 45%. The high minimum ratio was chosen because the quality of coconut shell charcoal is superior to dairy sludge as biomass, hoping it can meet the proximate and heat reference in SNI 01-6235-2000. Then, the adhesive ratio used was 5% - 10%. The Ministerial Regulation no. 047 of 2006 concerning bio-coal briquettes, the binder used is about 5%-10% [16]. The total composition of the four variables was 100%. The non-negativity condition is used to have no negative values when processing data using POM-QM.

c. Briquette Formulation Results

The overall formulation results are by the expected constraint function. The resulting formulation is 10% coal, 10% dairy sludge charcoal, 75% coconut shell charcoal, and 5% adhesive. Thus, the ratio of coal used in briquettes in this study can be reduced to a minimum of 10%, and the total biomass ratio can reach 85%.

3.2. Proximate Characteristics and Calorific Value of Briquettes

Based on the linear programming formulation, briquettes are made with a ratio of 10:10:75:5. The morphology of the briquettes is cylindrical, has a height of about 3 cm with a diameter of 4.5 cm. The dried briquettes will undergo an analysis process, including moisture content, ash content, volatile matter, bound carbon, and calorific value. A comparison of proximate characteristics and calorific value between POM-QM simulations with briquettes that have been made can be seen in Table 7.

Table 7. Comparison of Proximate Characteristics and Calorific Value (POM-QM and Briquettes)

Analisis	Moisture (%)	Ash (%)	Vollatile matter (%)	Carbon (%)	Calor (kal/gram)
POM-QM	10,43	17,27	5,88	-	6204,25
Charcoal	6	19	14	61	9247,41
Limit[a]	**≤8**	**≤8**	**≤15**	**≥69**	**≥5000**

a. Water content

There is a difference in water content between the POM-QM analysis and the briquettes made. Based on Table 7, the estimated water content of POM-QM is 10.43%, while in real conditions, it is only 6%. The low water content in the resulting briquettes is due to the drying treatment using an oven for 16 hours at a temperature of 105°C. The POM-QM estimate of 10.43% is thought to be the water content when the briquettes are wet, in the sense that before the drying process is carried out.

Drying with an oven at a temperature > 100°C tends to evaporate the material better. The briquettes that had been oven-dried for 16 hours at 80°C had a moisture content of 8.42% [17]. The formulated briquettes in this study have a low true moisture content (6%) due to oven drying for 16 hours at a temperature of 105°C. Thus, the water content of the briquettes in this study has complied with SNI 01-6235-2000, which is less than 8%.

b. Ash Level

There is a difference in ash content between the POM-QM analysis and the briquettes made. Based on Table 7, the estimated water content of POM-QM is 17.27%, while in real conditions, it is higher at 19%. Both estimates and real conditions, both have a value that is quite high and exceeds the limit. This means that the resulting briquettes have almost the same ash content as expected. The high ash content of the briquettes is caused by the materials used, mainly dominated by dairy sludge charcoal because it has an ash content of 68%.

This condition is similar to research conducted by Kwapinska and Leahy (2017) [10], that ash is the main constituent of dairy sludge charcoal produced from the pyrolysis process of around 70-80%. Hence, the ash content tends to be high. The study showed that the dairy sludge before pyrolysis had an ash content of 24.47, then increased after pyrolysis to 69.68%. This also happened in this study, where dry dairy sludge had an ash content of 28.5 and then increased after pyrolysis to 69.5. The use of dairy sludge charcoal is one of the factors causing the high ash content in the briquettes. Thus, the ash content of the briquettes in this study did not meet the limits of SNI 01-6235-2000 because it was more than 8%.

c. Volatile matter

There are differences in the volatile matter between the POM-QM analysis and the briquettes made. Based on Table 7, the estimated POM-QM volatile matter is 5.88%, while it is higher at 14% in real conditions. The high volatile matter in the resulting briquettes was caused by the lower water content of the briquettes compared to estimates. The lower the water content will increase the volatile matter, so the resulting briquettes have a higher volatile matter than expected.

This is following research conducted by Yuliah et al. (2017) [18], that briquettes with a moisture content of 36.01% have a volatile matter of 21.88%, while briquettes with a moisture content of 28.56% have a volatile matter of 25.61%. This is what supports that the lower the water content will increase the volatile matter. In addition, the high volatile matter can be influenced by the chemical components of charcoal, such as impurities [19]. However, the volatile briquette substance in this study still complies with SNI 01-6235-2000, which is less than 15%.

d. Bonded Carbon

Based on Table 7, the bound carbon obtained is 61%. Bonded carbon is not formulated in POM-QM because the bound carbon limit is not regulated in SNI 01-6235-2000. It would be nice when the percentage of bonded carbon could reach 69% because this figure is a calculation of bound carbon based on other proximate limits, where 100%-8%-8%-15% = 69%. Therefore, bound carbon is strongly influenced by water, ash, and volatile matter.

Research conducted by [19]) showed that high bound carbon is composed of low volatile matter. In this study, briquettes with 26.85% bound carbon had 46.3% volatile matter, while briquettes with 54.96% bound carbon had 24% volatile matter. Thus, the materials used also greatly affect the proximate characteristics produced. If the proximate characteristics other than bound carbon can be controlled properly, the bound carbon produced will be more maximal. It can even reach 69%.

e. Calorific Value

There is a difference in calorific value between the POM-QM analysis and the briquettes. Based on Table 7, the estimated calorific value of POM-QM is 6204.25 cal/gram, while the sample was 9247.41 cal/gram. The high calorific value is due to the good formulation of the materials used. The cause of the high calorific value is the use of coconut shell charcoal by 75%, which tends to dominate and the addition of coal by 10% also increases the calorific value.

In addition, water content is a proximate characteristic that strongly influences the calorific value. The same thing also happened, showing that briquettes with a moisture content of 8.42% had a calorific value of 6512.13 cal/gram. In comparison, briquettes with a moisture content of 17.12% had a heating value of 17.12%, calorific value of 5531.43%, both use the same tapioca adhesive ratio of 10% [17]. Therefore, the actual condition of the higher calorific value of the briquettes made when compared to the estimate is due to the low water content. Thus, the calorific value of briquettes in this study has met SNI 01-6235-2000, more than 5000 cal/gram.

4. CONCLUSION

The results showed that the optimal briquette formulations were 10% coal, 10% dairy sludge charcoal, 10% coconut shell charcoal, and 5% adhesive. Based on the formulation, overall, the briquettes have complied with SNI 01-6235-2000, but the ash content produced cannot meet the limits because one of the ingredients in the briquettes causes the high ash content is dairy sludge. The high ash content indicates that the minerals in the dairy sludge are also quite high. The relationship between the two is that the higher the mineral content, the higher the ash. However, this is not a crucial issue in this research. Still, the volatile matter becomes one of the targets that is quite important because the higher the volatile matter will be dangerous, in contrast to the ash content, which only leaves inorganic material (ash) after combustion. Compared with coal, the briquettes produced in this study have much better characteristics. They are even feasible to produce because they have a lower economic value when compared to commercial briquettes. Then, if viewed from the mass balance of the ingredients that have been made, dairy sludge tends to have a better charcoal yield of 44.35%. In comparison, coconut shell is only 27.8%, meaning that the decomposition process of dairy sludge is better than coconut shell.

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