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Original Research Article

Characterization of Fecal Sludge Combined with Sawdust as Briquettes

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Abstract

This study aimed to characterize fecal sludge (FS) combined with sawdust (SD) as non-charcoal briquettes. The combination consists of var.1 (FS 75% : SD 25%), var.2 (FS 50% : SD 50%), and var.3 (FS 25% : SD 75%). Fecal sludge was obtained from the sludge drying bed of a fecal sludge treatment plant (FSTP) in Malang City, and sawdust was obtained from the furniture workshop. Labor scale briquettes were produced, measured and analyzed the calorific value (ASTM D 5865-01), proximate analysis (SNI 06-3730-1995 and SNI 01-6235-2000), sulfur (ASTM D3177), and density (SNI 8021-2020). The characteristic results the moisture content 3.26%-7.57%, volatile matter 48.68%-68.97%, ash content 12.02%-32.97%, fixed carbon 11.44%–26.62%, calorific value 4,237.78–5.158.64 cal/g, sulfur 0.23%–0.41%, and density 0.50-0.68 (g/cm³). Compared with pure fecal sludge briquettes, the addition of sawdust increased the calorific value of fecal sludge briquettes by up to 32% and decreased ash content by up to 40%. All variations met the standard of SNI 8021:2020, except for the density for var.2 and var 3. Based on MCA, the best variation is var.2 with a score of 45 and requires modification for density to meet the standard of SNI 8021:2020.

Keywords: Bio-solid fuel; briquettes; characterization; fecal sludge; sawdust

1. Introduction

Malang City is one of the cities trying to improve the quality of latrines and expand the coverage of scheduled desludging services (SDS) and fecal sludge treatment plants (FSTP). Based on Indonesia Urban Water, Sanitation, and Hygiene (IUWASH) data of 2018, approximately 89% of Malang City residents have implemented proper sanitation through permanent healthy latrines, semi-permanent healthy latrines, and latrines integrated with communal septic tanks. The remaining 11% of the community does not have adequate sanitation facilities and is categorized as an open defecation (OD) practice (USAID, 2018a). Three of the five sub-districts in Malang City have been registered as SDS customers managed by the Local Government at a percentage of <20%, or approximately 18,337 households. Two other sub-districts have a 10%–15% subscription percentage or 5,075 households (USAID, 2018a). In this case, only about 11% or 23,412 households are SDS customers. On the other hand, SDS is provided by the private sector that serves the community and is integrated with the Supit Urang FSTP through Malang City Regional Regulation Number 2 of 2017 concerning Domestic Wastewater Management. However, the percentage of these services cannot be calculated with certainty (USAID, 2018b). The Supit Urang FSTP has an input capacity for fecal sludge of 90 m³/day, with an average daily processing of 57 m³/day – it still has an idle capacity (Wati, 2021). Commonly, 100% of the results from processing dried fecal sludge solids are produced as organic fertilizer, although the demand is generally lower.

Fecal sludge is defined as excrement that is usually stored in a local storage facility and periodically desludges and transported to the FSTP, and is expected to be disposed of or reused safely and adequately (Velkushanova et al., 2021). Fecal sludge generally contains high concentrations of organic matter and pathogens, which limits its use in the agricultural and plantation sectors due to environmental and health risks (Fakkaew et al., 2018). However, if fecal sludge can be appropriately managed, it has the potential to be a renewable energy resource (Krueger et al., 2020 & Ward et al., 2014) with a reasonably high energy content of 1,910.77–4,538.07 cal/g of dry-basis (Andriessen et al., 2019 & Muspratt et al., 2014). Other previous studies in Kumasi, Dakar, and Kampala (Muspratt et al., 2014) showed the calorific value of fecal sludge is 3,869.31–4,561.96 cal/g dry-basis. In Ghana, the potential of fecal sludge was tested as an environmentally friendly energy with a calorific value for dry fecal sludge of 3,620.91–3,778.54 cal/g and wet fecal sludge of 3,914.69–4,373.27 cal/g (Ahmed et al., 2019).

Compared to the calorific value of coal, which exceeds 6,687.69 cal/g, the potential of sludge is still relatively low. However, it can still be considered based on biomass fuel, which is more environmentally friendly and has sufficient calorific value for combustion. Fecal sludge is an applicable option. Compared to other biomass with a calorific value of 1,982.42–4,561.96 cal/g (Andriessen et al., 2019), fecal sludge is considered renewable. Dried fecal sludge can be directly burned, resulting in a high ash content of up to 58.5% (Gold et al., 2017), and is environmentally safe because of the lower emitted particulate matter than other biomass (Sanka et al., 2023). The carbonization of biomass generally increases the fuel value, but fecal sludge only increases the ash content by up to 70% (Hafford et al., 2018); therefore, carbonization is not the right option to increase the calorific value of fecal sludge. The strategy should be conducted by combining other biomass with a lower ash content and higher calorific value. This combination can reduce the ash content by 43–87% and increase the calorific value of fecal sludge by up to 90% (Kizito et al., 2022). Thus, this research used the sawdust as a biomass combination that is considered very advantageous due to its high calorific value of 4,210.85–4,304.00 cal/g (Lunguleasa et al., 2019), low ash content of 3.85% (Inegbedion, 2022), and can easily be obtained in furniture workshop as discarded waste.

This study offers a new objective for fecal sludge management in Indonesia by considering potential product utilization as an alternative resource recovery product in combination with sawdust. There are still few studies on the utilization of fecal sludge, while the most recent ones are only used as fertilizer. This study deserves attention as it explores the potential alternative utilization of fecal sludge as solid fuel and addresses the challenges of carbon tax policy and emission reduction in the energy sector through industry. It can also be adopted by other developing countries to reduce fecal sludge and wastewater pollution and support sustainable fecal sludge management.

This study examined fecal sludge as a solid fuel in the form of briquettes combined with sawdust through three variations of briquettes. The analysis carried out in this study included characteristic analysis and quality analysis according to SNI 8021:2020, and concludes the recommendation through multi-criteria analysis (MCA) through scoring and weighting. The results of this study should give local authorities in Malang City valuable information for planning future fecal sludge management and developing a circular economy from the fecal sludge management sector.

2. Methods

2.1 Sampling & Preparation

The sludge samples analyzed were obtained from the sludge drying bed of FSTP Supit Urang Malang City. The dried fecal sludge was estimated to be 14–30 days old with a moisture content of approximately 37.78%. Fecal sludge was taken randomly at six segments in the sludge drying bed (Barani et al., 2018) using a hoe, as shown in Figure 1. Samples were mixed, and 5 kg were packed in plastic sacks and brought to the laboratory of Talang Gulo landfill, Jambi City, to prepare briquette raw materials. Samples of sawdust with a moisture content of 18.99% were obtained from a local furniture workshop weighing as much as 5 kg, packed in plastic sacks, and brought to the same location as fecal sludge.

Figure 1. Sampling of fecal sludge in the sludge drying bed

Raw briquette materials (fecal sludge and sawdust) were prepared by shredding and sieving. The dried fecal sludge samples were shredded using a homemade organic crusher because of the hard and lumpy nature of the samples. After the dried fecal sludge samples were shredded and had a finer particle size, they were sieved using a 60 mesh sieve. The sawdust was pulverized using a grinder and sieved using a 60 mesh sieve. The conditioned samples were stored in a plastic box at room temperature in the Talang Gulo Landfill Laboratory.

2.2 Briquettes Production

Briquettes were made on a laboratory scale in the Landfill Laboratory of Jambi City by mixing fecal sludge and sawdust (Table 1). Starch was added as a binder at 5% of the total weight in the mixture of briquette materials. Starch was dissolved in a 1:3 ratio (1 g starch : 3 ml water). The mixed briquette material was molded into a metal tube with an inner diameter of 29 mm. The briquette material in the mold was compacted using manual drat compaction by rotating it to a certain density. Briquettes with a diameter of 29 mm and height of 30-40 mm were removed from the mold and dried. The molded briquettes were oven-dried at 105±5°C for 3 hours (Bekele Bayu and Beyecha Hundie, 2020 & Latebo et al., 2021). Briquettes that are still not dry can be dried again in the sun for 2–3 days.

Table 1. Briquettes Variations

Variation	Composition (% and weight)			
	Fecal Sludge	Sawdust	Binder	Water
-	100% (200 gram)	-	5% (10 gram)	15% (30 ml)
Var.1	75% (150 gram)	25% (50 gram)	5% (10 gram)	15% (30 ml)
Var.2	50% (100 gram)	50% (100 gram)	5% (10 gram)	15% (30 ml)
Var.3	25% (50 gram)	75% (150 gram)	5% (10 gram)	15% (30 ml)

2.3 Raw Material and Briquette Characterization

The raw materials for briquette products include fecal sludge and sawdust, characterized by calorific value, proximate analysis, and ultimate analysis. Raw material characterization aims to determine the initial content of each briquette raw material so that a comparison of the initial characteristics and the characteristics after being combined is obtained. The characterization of briquettes was carried out by testing the quality of briquettes based on proximate analysis, calorific content, % sulfur and density through the standard calorific value (ASTM D 5865-01), proximate analysis (SNI 06-3730-1995 and SNI 01-6235-2000), sulfur (ASTM D3177), and density (SNI 8021-2020). In specific, it was only the raw materials treated in the ultimate analysis based on ASTM D3176 with the following standard detailed: ASTM D3178 or D5373 for carbon and hydrogen, ASTM D3177 or D4239 for sulfur, ASTM D3179 or D5373 for nitrogen and determination of the oxygen value which is the remaining percentage of all parameters tested in the ultimate analysis. Proximate and density measurements were conducted at the Environmental Laboratory of Universitas Andalas. The ultimate analysis, calorific content, and sulfur content were measured at the Environmental Laboratory at Bandung Technology Institute.

2.4 Briquettes Quality Evaluation

In addition to analyzing and comparing the characteristics of fecal sludge briquettes with and without the addition of sawdust and to previous studies, the briquette quality was evaluated to determine its suitability as a solid fuel. The Indonesian Standard used for quality evaluation was SNI 8021:2020 (Table 2) for wood pellets because of the lack of a specific standard for fecal sludge briquettes. The evaluation is conducted by comparing the standards and characteristics of briquettes that consist of the parameters in the study scope. Fulfilling these standards is suitable for solid fuels.

Table 2. Fuel quality criteria on SNI 8021:2020

Parameter	SNI 8021:2020	
	First Quality	Second Quality
Moisture Content (%)	≤ 8	8 < x ≤ 12
Volatile Matter (%)	≤ 75	> 75
Ash Content (%)	≤ 2	> 2
Calorific Value (kal/g)	≥ 4,300	4,000 < x <4,300
Sulfur (%)	≤ 0.05	> 0.05
Density (kg/m³)	≥ 700	600 < x ≤ 700

2.5. Multi-criteria Analysis (MCA)

This study used the MCA to determine the most suitable briquette rank. These criteria were adopted from the study by Lohri et al. (2015). Generally, the criteria are divided into material availability and accessibility, and physical-chemical material properties. However, this study only considered the physical-chemical material property criteria and eliminated some criteria that were not available in this study, such as heavy metals, particle size, and impurity of materials, as shown in Table 3. Each briquette variation was scored using the available classified range. A high score addressed the favorable criteria value, while a low one addressed the unexpected value. For instance, a low moisture content is more favorable than a high one, so a high score will give to low moisture content. The criteria also provide weights based on the importance of energy recovery. The final score was derived from the sum of the scores and weights of all criteria. Briquettes with the highest total score were more suitable and recommended as solid fuels.

Table 3. Multi-criteria analysis

Criteria	Unit	Score 1	Score 2	Score 3	Score 4	Score 5	Weight
Moisture content	wt%	≥40	30 – 40	20 – 30	10 – 20	<10	3
Ash Content	wt% db	≥45	30 – 45	20 – 30	10 – 20	<10	3
Fixed Carbon	wt% db	≤10	10 – 11	12 – 13	14 – 15	≥16	1
Calorific Value	MJ/kg db	≤12	13 – 14	15 – 16	17 – 18	≥19	3
Density	kg/m^3	≤300	300 – 450	450 – 600	600 – 750	>750	1

3. Result and Discussion

3.1 Raw Material Characterization Results

A previous study found that the carbonization of fecal sludge has a disadvantageous impact. If biomass carbonization generally increases the fuel value, fecal sludge will only increase the ash content by up to 70% (Hafford et al., 2018); therefore, carbonization is not the right option to increase the calorific value. To increase the parameter value of fecal sludge, combining it with biomass (sawdust in this study) with a higher calorific value and lower ash content is necessary. The raw materials proximate, ultimate, and calorific values were analyzed, as shown in Table 4. The moisture content of fecal sludge is higher than the sawdust because of the high moisture content of fecal sludge before treatment at the FSTP. The treatment of fecal sludge was conducted using sand filtration and a drying bed. Hence, a higher moisture content is characteristic of fecal sludge. This is in contrast to sawdust, which, in principle, has a fairly dry condition.

Table 4. Fecal sludge & sawdust characterization as raw material

No	Parameter	Raw Material	
		Fecal Sludge	Sawdust
1	Moisture content (%)	37.78	18.99
2	Volatile Matter (%)	22.80	60.69
3	Ash content (%)	31.82	1.17
4	Fixed Carbon (%)	7.61	19.14
5	Carbon (%)	49.13	41.49
6	Hydrogen (%)	6.71	4.98
7	Oxygen (%)	24.4	39.22
8	Nitrogen (%)	5.18	0.52
9	Sulphur (%)	0.83	0.13
10	Calorific Value (cal/g)	3,514.44	4,687.12

The moisture content of fecal sludge obtained in this study is also quite high when compared to related studies in Brazil and Uganda, which are around 7.10%-14.11% (de Oliveira et al., 2017 & Kizito et al., 2022). When compared to the study results of several Indian cities, namely Haridwar, Dehradun, Lucknow, Unnao, and Jhansim, which have a moisture content in dry sludge of 22%-48%, the moisture content of fecal sludge in this study is still within the range. The difference in moisture content is due to several factors: the initial moisture content of the sludge brought to the STP that is closely related to the type of toilet, containment, or latrine used; the length of storage, inflow, and infiltration to the environment; the desludging method; the weather/climate conditions in the area; the desludging method; and the treatment mechanism used (Strande et al., 2014), such as open or semi-open, porosity, and saturation level of filtering sand. It is better to have a lower fuel moisture content so the energy can be optimally utilized in the combustion process without first reducing the moisture content. A comparison of the results of this study with those of similar studies is presented in Table 5.

Table 5. Fecal sludge characteristic from another study

Study Location	Moisture Content (%)	Volatile Matter (%)	Ash Content (%)	Fixed Carbon (%)	Calorific Value (cal/g)	Sulfur (%)
Malang, Indonesia (This Study)	37.78	22.80	31.82	7.61	3,514.44	0.83
Boulder, USA	-	42.70–61.10 [a]	36.80–51.20 [a]	0.40–6.20 [a]	2,483.99 – 3,487.15 [a]	
Kampala, Uganda	8.10 [b]	-	58.70 [b]	-	2,603.42 – 3,702.11 [a] 2,603.42 [b] 3,869.31 [c]	0.70 [b]
Dakar, Senegal	6.70 [b]	-	47.00 [b]	-	3,200.54 [b] 3,964.84 [c]	
Dutch	-	58.50±5.00 [i]	41.30±8.90 [i]	11.80±6.60 [i]	3,224.42 ± 358 [i]	
Kumasi, Ghana	-	-	-	-	4,561.96 [c]	
Accra, Ghana	-	-	-	-	3,620.91 – 3,778.54 [d]	
Uganda	7.10±1.40 [e]	28.85±0.33 [e]	55.35±1.34 [e]	8.70±1.20 [e]	1,478.46±217 [e]	
Brazil	14.11 [f]	-	-	-	3,179.04±45 [f]	
Tamil Nadu, South India	-	26.50–47.70 [g]	39.00–69.30 [g]	3.20–11.40 [g]	1,289.77 – 3,200.54 [g]	0.80–1.10 [g]
Jaipur, India	-	-	-	-	3.514,44	

Source: [a] (Hafford et al., 2018); [b] (Gold et al., 2017); [c] (Muspratt et al., 2014); [d] (Ahmed et al., 2019); [e] (Kizito et al., 2022); [f] (de Oliveira et al., 2017); [g] (Barani et al., 2018); [h] (Sharma et al., 2020); [i] Phyllis2.

Unlike the moisture content, the volatile matter of fecal sludge is lower than sawdust at 22.80%. The low volatile matter is in line with the H_2, CO, CO_2, and H_2O contents of the fecal sludge, which are also low. This affects the ignitability of the fecal sludge, as the higher the volatile matter, the easier the fuel ignition process (Saputro and Widayat, 2016). The volatile matter of fecal sludge in this study was also lower compared to similar studies in the range of 28.85%-61.10% (Barani et al., 2018; Hafford et al., 2018; Kizito et al., 2022). The higher the volatile matter, the higher the particulate emissions (PM) in the combustion process, poor performance in the gasification process, low temperature, and increased CO_2 emissions (Ilham, 2021).

The ash content of fecal sludge is very high compared to sawdust, with a more than 30% difference. The other studies found a much higher ash content in fecal sludge than in this study, which was 47.00%-55.35% (Barani et al., 2018; Gold et al., 2017; Kizito et al., 2022). The high ash content could be caused by a residue mixture, such as sand, in the sludge drying bed at the FSTP. The ash content of fecal sludge analyzed in previous studies was used as a basis for determining the combination/mixing of other biomass feedstocks when fecal sludge is utilized as a solid fuel. In other words, fecal sludge needs to be mixed with biomass with a much lower ash content; therefore, sawdust with an ash content of 1.17% was used in this study. The fecal sludge briquette was not carbonized due to the carbonization process increasing the ash content of the fecal sludge by up to 70% (Hafford et al., 2018).

The fixed carbon content of fecal sludge found in this study was higher than that Barani et al. (2018) reported at 3.70%–4.10% and Kizito et al. (2022) at 7.10%. Compared to sawdust, this fixed carbon content is lower, at only approximately 7.61%. The amount of fixed carbon is highly dependent on the type of biomass and the ash content (Tag et al., 2016). In other words, the lower the ash content of the biomass, the higher the value of fixed carbon, which can benefit the utilization process as a bio-solid fuel.

The results of the ultimate analysis of the briquette feedstock showed that fecal sludge had the highest values of carbon, hydrogen, nitrogen, and sulfur parameters at 49.13%, 6.71%, 5.18%, and 0.83%, respectively, compared to sawdust. As for the oxygen parameter, fecal sludge had the smallest value (24.4 %). The carbon, hydrogen, nitrogen, oxygen, and sulfur values of fecal sludge in this study were consistent with the values obtained by Hafford et al. (2018), which were 49.70%, 6.20%, 5.00%, 22.40%, and 0.80%, respectively. Barani et al. (2018) found that all the ultimate analysis parameters were lower than those in this study, except for sulfur, which was 26.20%–33.40% for carbon, 3.50%–4.20% for hydrogen, 2.60%–4.50% for nitrogen, and 9.30%–17.00% for oxygen, while the sulfur value was higher at a percentage of 1.30%–1.50%.

The calorific value is a parameter used in fuel characterization. The calorific value of the fecal sludge as a briquette raw material was 3,514.44 cal/g. This value is much lower than sawdust of 4,687.12 cal/g. The calorific value obtained in this study was higher than that reported by Barani et al. (2018) 2,149.61–2,627.31 cal/g and Gold et al. (2017) 2,603.42-3,200.54 cal/g. In this study, the sample was taken from an active treatment pond; the calorific value obtained follows the previous study in Kumasi, Ghana, which is 3,487.15 cal/g (Muspratt et al., 2014). This value is lower than the calorific value range of 3,869.31-5,015.77 cal/g for fresh dried feces samples before treatment at FSTP (Barani et al., 2018; Muspratt et al., 2014). The difference in calorific value may be due to the influence of sand, which is potentially present in the desludging, collection, and use of sand in the dewatering process at the FSTP (Seck et al., 2015). Other factors include the breaking of energy bonds in organic materials, which are easily decomposed over time, and the potential mixing of inert materials (Andriessen et al., 2019).

3.2 Briquettes Characterization Results

Briquette products were characterized by analyzing the proximate, calorific, and sulfur values. The characterization results of the briquette products are listed in Table 6.

Table 6. Briquettes characteristics

No	Variation	Moisture Content (%)	Volatile Matter (%)	Ash Content (%)	Fixed Carbon (%)	Calorific Value (cal/g)	Sulfur (%)	Density (g/cm³)
-	FS 100%	4.27	38.75	51.91	5.07	3,921.43	0.64	0.88±0.12
Var.1	FS 75% : SD 25%	3.26	51.34	32.97	12.42	4,237.78	0.41	0.68±0.05
Var.2	FS 50% : SD 50%	7.09	48.68	17.61	26.62	4,693.11	0.33	0.56±0.03
Var.3	FS 25% : SD 75%	7.57	68.97	12.02	11.44	5,158.64	0.23	0.50±0.09

The moisture content of this combination of briquettes tended to increase to 7.57%. A high moisture content will impact the low heat of combustion (Magnago et al., 2020). However, this moisture content is still acceptable according to the recommendation for application of no more than 10% before combustion (Yank et al., 2016).

The combination in this study increased the volatile matter up to 68.97%. The increase in volatile matter in blending fecal sludge and biomass is inevitable, even up to 74% (Kizito et al., 2022). Volatile matter is generally part of the fuel released as gas at a specific temperature and accounts for most of the heat generated during combustion (Avelar et al., 2016). In addition to affecting the amount of gas emissions, high levels of volatiles burned through the embodied energy of the fuel also affect the residual energy used to generate heat energy (Kpalo et al., 2021).

The ash content of pure fecal sludge briquettes (FS 100%) was much higher than that of the raw fecal sludge. This could be caused by the possibility of sand contamination that has been mixed in the sludge because the samples were taken at the FSTP Supit Urang in Malang City. Purifying fecal sludge as briquette feedstock is difficult because the homogeneity process is performed by equalizing the sample size on a 60-mesh sieve. A high ash content will not help the combustion process and will only result in a decrease in calorific value (Avelar et al., 2016 & Kizito et al., 2022); therefore, the ash content will only contribute to the increase in dust and toxic substances in the environment (Kpalo et al., 2021). Combining fecal sludge with biomass will reduce ash content by up to 39.89% in this study and up to 87% in previous studies (Kizito et al., 2022). A reduction in ash content was also considered to increase the calorific value by up to 53% (Turyasiima et al., 2016).

Compared to pure fecal sludge briquettes (FS 100%), the combined briquettes of fecal sludge and sawdust showed an increase in calorific value of up to 32%, namely 4,237.78-5,158.64 cal/g. This value is quite higher compared to the combination of fecal sludge with other biomass such as carbonized sawdust, charcoal dust, coffee husk, pea husk, pineapple peel, and carbonized cow dung in previous studies, which can reach a calorific value of 3,200.54–4,155.92 cal/g (Kizito et al., 2022; Nyaanga et al., 2018; Sharma et al., 2020; Turyasiima et al., 2016). High calorific values are usually characterized by low volatile matter and high fixed carbon content (Idowu et al., 2020 & Kpalo et al., 2021). However, this is not always the case, as other factors can potentially affect the calorific value of the fuel (Kizito et al., 2022).

3.3 Quality Evaluation based on SNI 8021:2002

Briquette quality was evaluated by comparing the provisions/standards set out in the SNI with the values obtained from the results of the characteristics test. The SNI evaluation included several parameters, namely moisture content, volatile matter, ash content, calorific value, sulfur content, and density. SNI generally regulates two types of fuel quality: first quality and second quality. Each briquette variation was compared with SNI 8021:2020 and is shown in **Figure 2–6.**

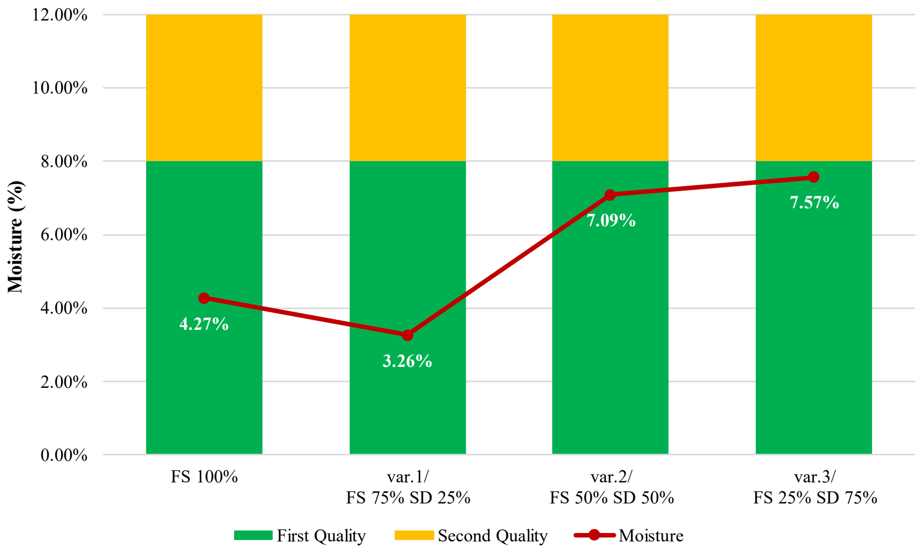


Figure 2. Evaluation of briquette moisture content with the provisions of SNI 8021: 2020

The first quality of SNI 8021:2020 regulates the moisture content value ≤8%, whereas the second quality is 8% < x ≤ 12%. Based on the results of the characteristic test, all variations of briquette samples met the first quality standard of moisture content in this SNI, with a range of values from 3.26%-7.57%. All the briquette samples were suitable as fuels for the moisture content parameter.

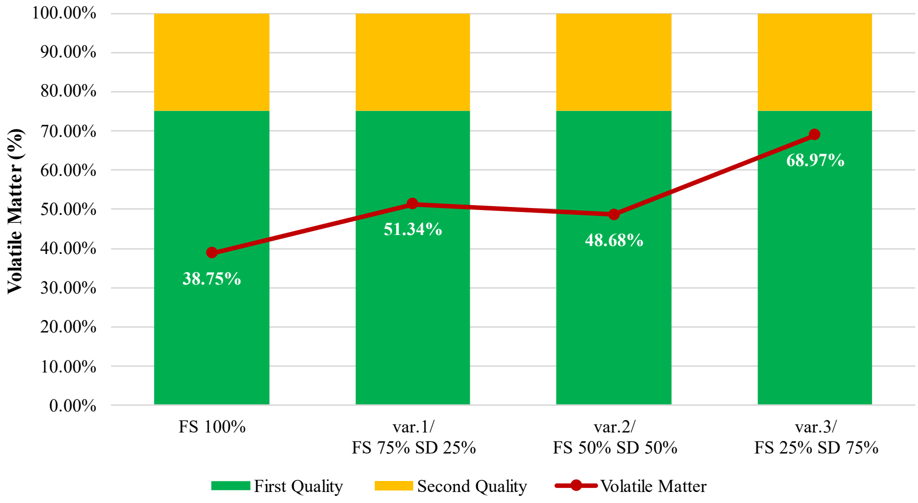


Figure 3. Evaluation of volatile matter of Briquettes with the provisions of SNI 8021: 2020

The volatile matter in the first quality SNI 8021:2020 was ≤75%, while that in the second quality was >75%. When compared with the results of the characteristic test, all variations of briquette samples have volatile matter <75% or can be stated to meet the first quality standard of this SNI with a value range of 48.68%- 68.97%. All the briquette samples were suitable as fuels for the volatile matter parameter.

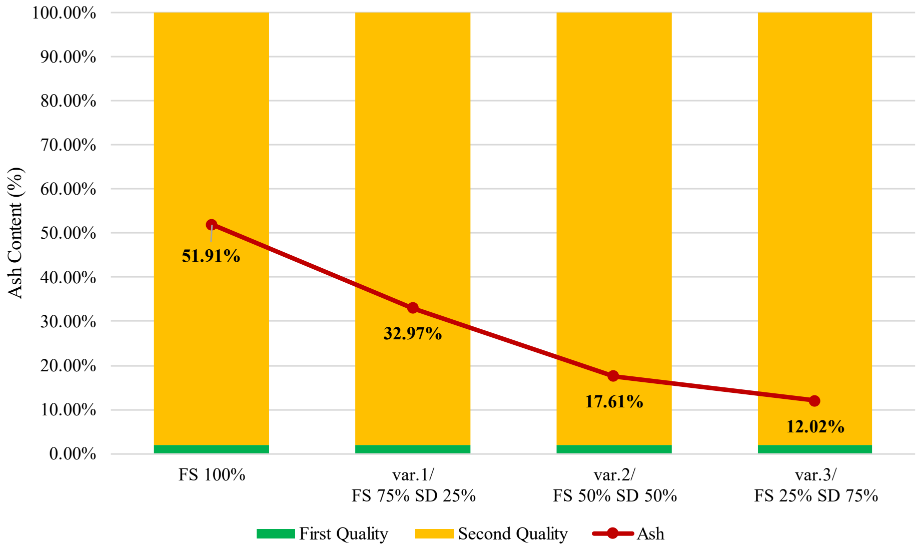


Figure 4. Evaluation of briquette ash content with the provisions of SNI 8021: 2020

The first quality of SNI 8021:2020 regulates an ash content of ≤2%, whereas the second quality is >2%. Based on the results of the characteristic test, all variations of briquette samples met the second quality standard of ash content in this SNI, with a range of values from 12.02%-32.97%. For the ash content parameter, all briquette samples were suitable as fuels; however, the lowest ash content value was more feasible.

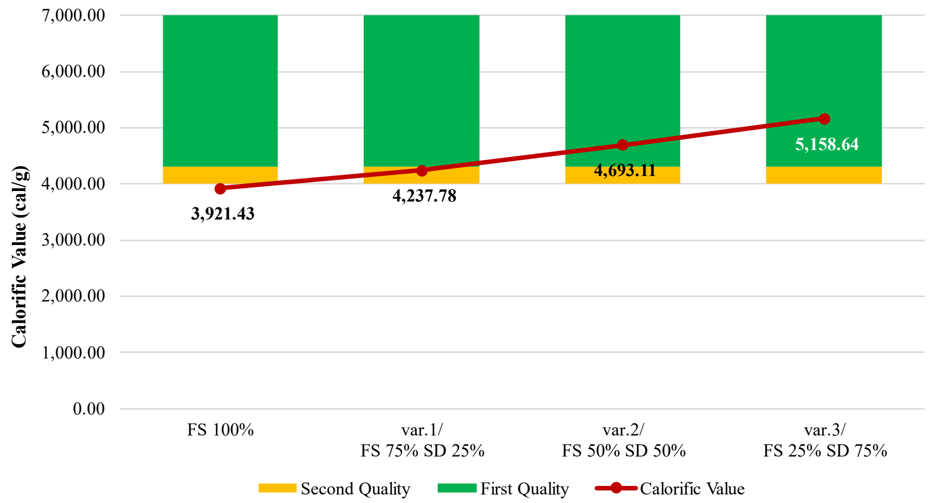


Figure 5. Evaluation of briquette calorific value with the provisions of SNI 8021: 2020

Calorific value in the first quality of SNI 8021:2020 is ≥4,300 cal/g while the second quality is 4,000 < x < 4,300 cal/g. When compared with the results of the characteristic test, there were two variations of briquette samples that met the first quality in the range of 4,693.11-5,158.64 cal/g. One sample variation (var.1/ FS 75% SD 25%) successfully met the second quality criterion with a value of 4,237.78 cal/g or almost met the first quality criterion. FS 100%, on the other hand, was still below the regulated quality criteria, but almost met the second quality criteria.

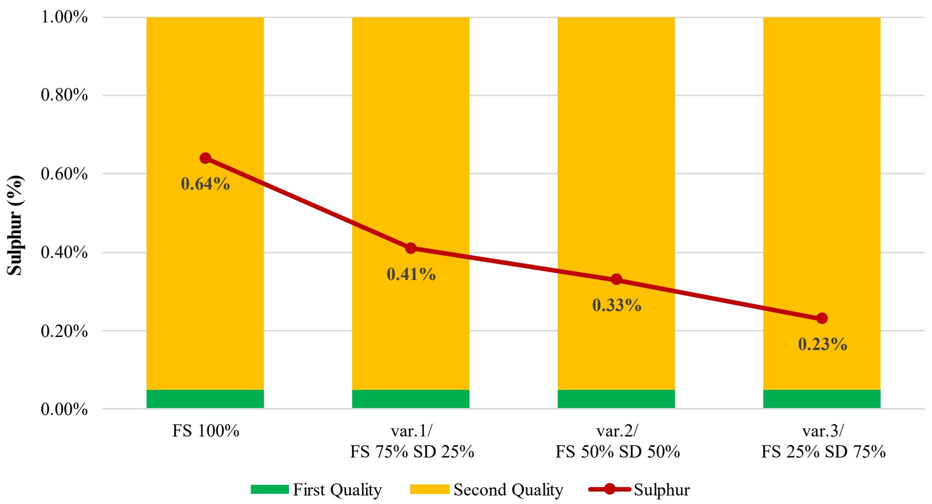


Figure 6. Evaluation of sulfur briquettes with the provisions of SNI 8021: 2020

The first quality of SNI 8021:2020 regulates the sulfur value to ≤0.05%, whereas the second quality is > 0.05%. Based on the results of the characteristic test, all variations of briquette samples met the second quality standard of sulfur content in this SNI, with values from 0.23%-0.41%. All briquette samples are suitable as fuel for the sulfur parameter, but the lowest sulfur value or close to the first quality is safer to use as fuel.

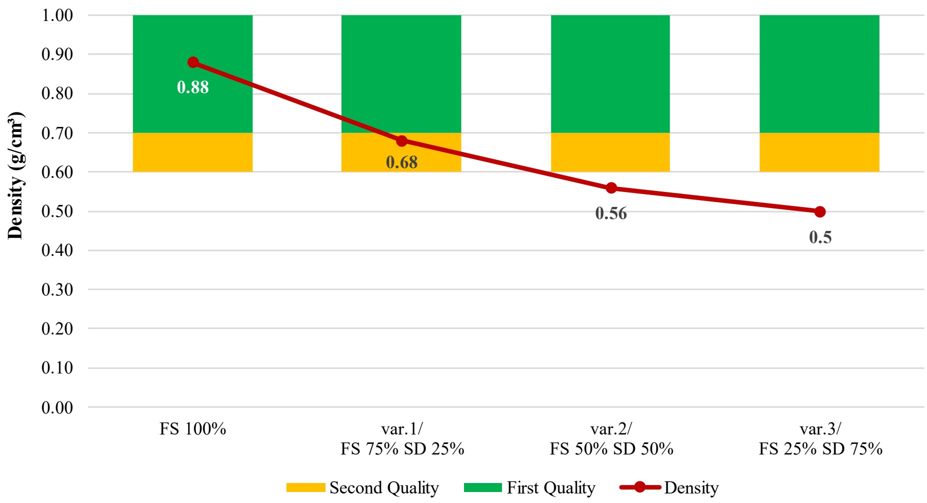


Figure 7. Evaluation of briquette density with the provisions of SNI 8021: 2020

The density value in the first quality of SNI 8021:2020 was ≥ 700 kg/m³, whereas the second quality was 600 < x ≤ 700 kg/m³. When compared with the results of the characteristic test, one sample variation (var.1/ FS 75% SD 25%) successfully met the second quality criterion with a density value of 680 kg/m³. The remaining two sample variations, var.2/ FS 50% SD 50% and var.3/ FS 25% SD 75%, were below the regulated quality criteria.

Table 7. Recapitulation of quality evaluation based on SNI

	Parameter	FS 100%	Var.1/ FS 75% SD 25%	Var.2/ FS 50% SD 50%	Var.3/ FS 25% SD 75%
SNI 8021:2020	Moisture	✓	✓	✓	✓
	Volatile Matter	✓	✓	✓	✓
	Ash Content	✓	✓	✓	✓
	Calorific Value	✗	✓	✓	✓
	Sulphur	✓	✓	✓	✓
	Density	✓	✓	✗	✗

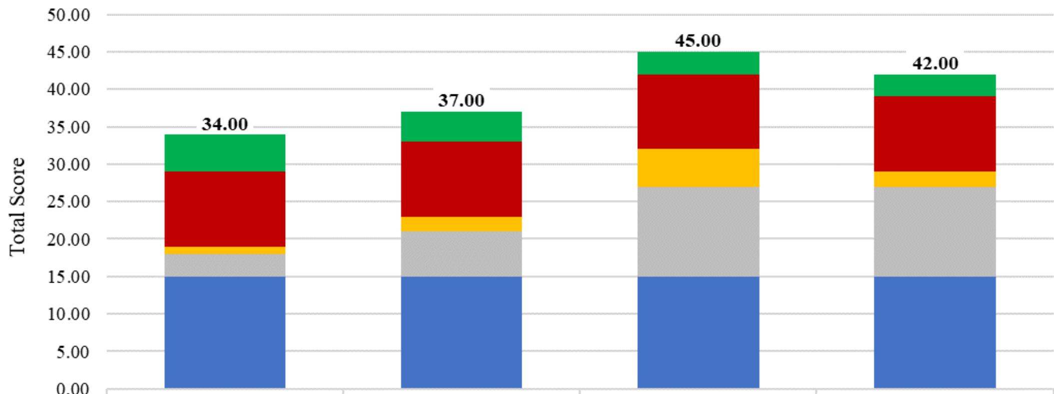
Based on the quality analysis of the three samples, two samples (var.2 and var.3) still have deficiencies in the density parameter. This can be due to the non-optimal manual compaction for compacting briquette, so the density does not meet the desired SNI standards. The strength of the press influences the density of the briquette; the higher the compressive strength of the press, the better the density of the briquette (Rinanda et al., 2021). The particles fill the empty spaces in the briquette through compaction, thereby reducing its pores and increasing its density (Rinanda et al., 2021 & Titarsole and Fransz, 2023). However, excessive compressive strength results in cracking of the briquettes. The optimal compressive strength is no more than 150-200 bar (Kurtyka et al., 2022 & Rinanda et al., 2021).

In addition to the influence of compressive strength, the particle size of the raw materials significantly influences the density of briquettes (Anggraeni et al., 2021; & Antwi-Boasiako and Acheampong, 2016). The finer and denser the raw materials, the denser the briquettes with an optimal density (Afna et al., 2021 & Mahajoeno, 2005). According to the raw material, the sawdust content in the samples had a fairly fine texture but tended to be light. A larger volume of sawdust is required to produce a weight composition according to the provisions of sample variation. The density of sawdust as a raw material is also considered small, ranging from 0.22-0.25 g/cm³ with a high porosity of 71%-77% (Maharani et al., 2010). The condition of the raw material is also the cause of the lower density in var.2 And var.3. Similar studies of briquettes containing a mixture of fecal sludge and sawdust found a lower density of 0.333 g/cm³ (Turyasiima et al., 2016), whereas other studies focused only on sawdust briquettes found similar and higher densities in the range of 0,440–1,104 g/cm³ (Antwi-Boasiako and Acheampong, 2016; Bello and Onilude, 2020; Ramírez-Ramírez et al., 2021).

Optimal briquette density affects the strength of briquettes (Somerville, 2016), especially in the transport and distribution of briquettes. Therefore, the use of var.2 and var.3 as solid fuels needs to be improved in the density parameter. The recommendations proposed to improve the quality of var.2 and var.3 briquette density include evaluating the compressive strength of the compaction so that it can be more optimal, including the amount of compressive strength, length of time for compaction, automation of compaction, and optimal temperature when compaction; evaluating the fineness of raw materials to obtain the optimal particle size; and evaluating the appropriate size of the briquette mold so that the briquettes are not brittle and do not crack.

3.4 Recommendation through Multi-criteria Analysis

In addition to comparing the product characteristics of fecal sludge briquettes and biomass combinations with SNI, the selection of the best variation of briquettes was carried out through scoring and weighting using multi-criteria analysis (MCA) (Lohri et al., 2015) to obtain the best variation combination that is more feasible to utilize. The scoring and weighting results are shown in Figure 8.



	FS 100%	var.1/ FS 75% SD 25%	var.2/ FS 50% SD 50%	var.3/ FS 25% SD 75%
Density	5.00	4.00	3.00	3.00
Calorific Value	10.00	10.00	10.00	10.00
Fixed Carbon	1.00	2.00	5.00	2.00
Ash Content	3.00	6.00	12.00	12.00
Moisture	15.00	15.00	15.00	15.00

Figure 8. Results of scoring and weighting of briquette sample variations through MCA

The results of scoring and weighting are ranked from the largest total value to the smallest, resulting in a ranking for each briquette variation. The first ranked is var.2/ FS 50% SD 50% with a total score of 45, the second-ranked is var.3/ FS 25% SD 75% with a total score of 42, and the third-ranked is var.1/ FS 25% SD 75% with a total score of 37. The var.2/ FS 50% SD 50% is recommended as the best sample according to the MCA assessment results so that it can be considered in the future for utilizing a combination of fecal sludge and sawdust in briquettes.

4. Conclusions

Sawdust addition to fecal sludge briquettes increased the calorific value to 32% or 5,158.64 cal/g. This addition also increased the moisture content, with the lowest moisture content by var.1 of 3.26%. The characteristics of fecal sludge with high ash content greatly benefit from the combination of sawdust. Therefore, the ash content of the mixed briquettes decreased by up to 40%. The volatile matter and fixed carbon do not have a linear correlation with the briquette variation, i.e.,48.68%-68.97% and 11.44%-26.62%, respectively. The sulfur value met the second quality standard of SNI 8021:2020, 0.23%-0.41%. Based on the MCA, the best variation that can be recommended is var.2. Due to the high score, it obtained considering the SNI 8021:2020, it still needs to tighten the density because it cannot meet the criteria of SNI 8021:2020. This study found that fecal sludge in Malang City has the potential to be used as a bio-solid fuel, and sawdust as combined biomass can increase several parameters of the required fuel criteria.

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