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Characteristics of Density and Hardness on Caloric Value of Substitution of Biomass and Pet Plastics as Refused Derived Fuel Pellets

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Abstract

The utilization of biomass and polyethylene terephthalate (PET) waste as raw material for refuse-derived fuel (RDF) has been studied. However, physical such as density and hardness are still not widely used. This study aimed to determine the relationship between variations in the composition of PET and physical garden waste density and hardness on the quality of the caloric value of RDF. Density measurements were carried out with the Ultrapyc 1200e instrument. While for hardness, using the Shore D method. The Shore D Hardness test is a standardized test that involves evaluating the amount of depth that may be penetrated by a certain indentation. The lowest density is RDF pellets for food waste at 1,537 kg/m^3 and consists of RDF pellets for plastic waste at 2,560 kg/m^3. In line with the density, the hardness value increases with the addition of the PET composition. The density and hardness values in the RDF mixture show a simultaneous relationship to the heating value. The highest caloric value achieved is the use of 100% PET as pellets which can reach 5765 kcal/kg.

INTRODUCTION

Biomass is organic material produced through photosynthetic processes in the form of plants, trees, grass, sweet potatoes, agricultural waste, and forest waste. Biomass is generally used as a primary fiber, food, animal feed, vegetable oil building material, etc. In addition, biomass can also be used as a renewable energy source to provide sustainable energy (Afifah et al., 2020; Danish & Wang, 2019; Gasim et al., 2022; Raksasat et al., 2021; Suryawan, Septiariva, et al., 2022). Indonesia has begun to develop biomass into pellets as an application in the coal substitute industry (cofiring) and an alternative material to replace Liquid Petroleum Gas (LPG) on a household scale (Pradnyaswari et al., 2022). The utilization of biomass is still not enough to increase the calorific value, therefore one of the materials that can increase the calorific value is plastic such as PET (Abnisa & Wan Daud, 2014).

PET plastic is a polyester resin that is durable, lightweight, strong, and easy to shape under hot conditions. PET is better suited than polyolefins and PVC for recycling operations aimed at the resynthesis of virgin plastics or upcycling to higher-value products (Sales et al., 2021). PET has an estimated annual global production of more than

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70 million tons, with its major applications being textile fibers and packaging (Crippa & Morico, 2020). The processing of PET plastic waste is widely used as a recycled product to produce items of economic value, such as making them into crafts, decorations, and bags and being processed into plastic ore (Sari et al., 2022). PET plastic is a polymer that can be used as a fuel. Plastic has the potential as a fuel in incinerators or is used as RDF because it has a high caloric value (Syguła et al., 2021). PET plastic functions as a binder (adhesive), which helps in the properties of RDF pellet from the caloric value, moisture content, ash content, and combustion exhaust gases.

The physical properties of RDF substitution cover comprehensive aspects. However, information on the physical properties of RDF is still limited (Suryawan, Fauziah, et al., 2022).In other hand, plastic have been possibly employed as a resource through urban mining for energy recovery operations as RDF (Gunjan et al., 2021). This research is still rare even though it is imperative as a basis for optimal use of density and hardness in the form of pellets. Density is the mass of a particle that occupies a certain unit volume. Density is used to determine the compactness and texture of the feed. A compact feed texture will be resistant to the influence of the pressing process so that the bond between the particles making up the feed becomes very strong, and the space between the particles of the feed material is not filled with air cavities. This study aimed to determine the characteristics of the mixture of biomass and PET waste on the heating value of RDF pellets based on the physical pellets in the form of density and hardness.

MATERIALS AND METHODS

Table 1 shows the variation of the waste mixture used in RDF processing. The variation on this research including PP0, PP25, PP50, PP75, and PP100. In the printing process, a mechanical process involves heat and pressure, which aims to solidify the materials through holes in the pelletizing machine. The pellet molding machine has an optimum temperature of around 60-800°C, making the pellets dense, dry, and shiny (Figure 1).

After doing the pellet molding process with 25% interval variation, the pellets were dried under the sun. The drying process aims to reduce the water content so that the RDF pellets are protected from mold growth, and the pellets are denser and do not break easily.

Table 1. The mixture of PET and garden waste in RDF pellet.

Name Variation	PET Waste (%)	Garden Waste (%)
PP0	0	100
PP25	25	75
PP50	50	50
PP75	75	25
PP100	100	0

Figure 1. Example of RDF pellet.

The density analysis was tested by first running the Ultrapyc 1200e instrument. The sample container is inserted into the cell and tightly closed, then click the sample on the Quantachrome pycWeb. After that, the running process is carried out by pressing the 1 button and then pressing the three buttons to start on the Quantachrome pycweb key. The Quantachrome Ultrapyc instruments are the most precise tools available for determining the actual volume and density of powders, foams, and bulk solids. The tool will analyze the sample, and the results will come out when the analysis has been completed.

The hardness test here uses the shore test. This test uses a pressure gauge with a sharp needle, the Teclock GS-720N type D. For polymers, two measurement scales are Shore D for plastic or hard rubber and Shore A for soft rubber. Shore D uses a conical suppressor held in place by a calibrated spring. The Shore D value shows the depth of penetration imposed on the surface of the test material. The durometer test tool uses the Shore D Hardness method, which refers to the standard size of the American Society for Testing and Materials (ASTM) D2240-15 test with a length of 80 mm, a width of 70 mm, and a thickness of 6 mm. The hardness test on each sample was carried out three times, then averaged.

Table 2. Density and hardness values on RDF pellet mixture of PET and biomass.

Variation	Density (kg/m^3)			Average	Stdev	Hardness (HA)			Average	Stdev
PP0	1,462	1,602	1,547	1,537	70.64	43	42	46	44	2.08
PP25	2,206	2,253	2,191	2,216	32.48	47	46	46	46	0.58
PP50	2,303	2,327	2,368	2,333	32.73	52	50	48	50	2
PP75	2,410	2,381	2,461	2,417	40.54	54	51	51	52	1.73
PP100	2,658	2,444	2,577	2,560	107.79	52	53	54	53	1

The RDF samples are placed in an oxygenated tube immersed in a heat-absorbing medium (calorimeter), then the sample will burn. In this study, all variations of RDF pellets were measured with a bomb calorie meter to determine how much caloric value each variation had. The hypothesis testing used is a Multiple Linear Regression analysis tool in this research. Multiple linear regression is a regression model that involves more than one independent variable. A multiple linear regression test was used to determine the effect of several independent variables on the dependent variable (Y), namely the caloric value. The value of R2 is very high, but individually many independent variables do not significantly affect the dependent variable. If there is a reasonably high correlation between independent variables (above 0.90), this indicates multicollinearity.

RESULTS AND DISCUSSION

The results of the density and hardness calculations are carried out by determining the volume on the RDF pellet according to the research method, then weighing the mass. Shocks within the container, shocks to the container when it is being transported, or collisions with another container in another location can all cause changes in the harness and density of the RDF pellet material (Suryawan, Fauziah, et al., 2022). After obtaining the mass and volume, calculations are carried out using the density formula, namely mass divided by volume. The density and hardness of each variation can be seen in Table 2. The density of the pile of materials affects the mixing and dosing power automatically and the specific gravity. This property also plays an essential role in calculating the volume of space required for a material with a certain density, such as filling mixers, elevators, and silos. Mixing materials with the same particle size, but having a pile density of more than 500 kg/m^3 or 0.5 g/cm^3 (Duan et al., 2019), these materials are difficult to mix and easily separate again. The standard from several countries for several countries, such as the Austrian Standard (ONORM M 7135) is >1.120 kg/m^3. The Swedish Standard (SS 18 71 20) is >600 kg/m^3, American Standard (PFI)* >640 kg/m^3, and French Standard (ITEBE) >1,150 kg/m^3 (Bantacut et al., 2013).

The caloric value of fuel is the maximum amount of heat energy released by a fuel through a complete combustion reaction per unit mass or volume (Paraschiv et al., 2020; Reis et al., 2019). Analysis of the caloric value of a fuel is intended to obtain data on the heat energy that fuel can release by a reaction or combustion process (Jenkins et al., 1998). Factors that may cause differences in the percentage of water content in the sample RDF can be because of uneven RDF pellet dough so that the water content is different. Table 3 shows the larger PET will increase caloric value.

Table 3. Caloric value of RDF Pellet Mixture of PET and Biomass.

Variation	Caloric Value (kkcal/kg)
PP0	3683
PP25	4853
PP50	5185
PP75	5416
PP100	5765

Based on the Pearson correlation test results, the effect of hardness values on RDF greatly affects the characteristics of the heating value of RDF pellets show in Table 4. The high-density value affects the decrease in the water content value caused by the pressure in the modified through-hole getting a different pressure and causing water to come out of the RDF pellet. Which impacts the smaller pellet pores so that the RDF pellet will have difficulty absorbing the moisture content. The low water content has a positive impact on the caloric value. The lower the water content value, the higher the caloric value (Koko et al., 2022; Sarwono et al., 2021; Suryawan, Septiariva, et al., 2022; Zahra et al., 2022). This is due to the low moisture content of the wood pellets, resulting in the tapioca adhesive

Table 4. Pearson correlation value of RDF pellet mixture of PET and biomass.

Correlations		**Caloric Value**	**Density**	**Hardness**
Pearson Correlation	Caloric Value	1	0.994	0.932
	Density	0.994	1	0.891
	Hardness	0.932	0.891	1
Sig. (1-tailed)	Caloric Value	.	0	0.011
	Density	0	.	0.021
	Hardness	0.011	0.021	.

Table 5. Value of caloric value estimation model for RDF pellet mixture of PET and biomass.

Model	Unstandardized Coefficients	Std. Error	Standardized Coefficients	t	VIF
	B		Beta		
(Constant)	-6638.53	870.98		-7.622	
Density*	-0.34	1.219	-0.079	-0.279	4.839
Hardness*	249.868	66.18	1.072	3.776	4.839
R	0.999				
R Square	0.998				
Adjusted R Square	0.997				

*Is significance at $p < 0.01$

Table 6. ANOVA model of estimating caloric value for RDF pellet mixture of PET and biomass.

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	2542568.577	2	1271284.288	608.504	0.002
Residual	4178.395	2	2089.198		
Total	2546746.972	4			

being able to bind the sawdust well and filling the empty cavities in the RDF pellet, thereby reducing water particles in the RDF pellet.

The presence of fine fibers can cause the flat surface with fine cracks. The complete caloric value of RDF, a mixture of PET and biomass. Which consists of physical qualities of density and hardness, significantly affects the increase in caloric value in RDF. Multiple linear equations also show p-value < 0.01 for both density and hardness variables show in Table 5. This is in line with previous research that stated that density and hardness are also key parameters in RDF quality (Suryawan, Fauziah, et al., 2022). The water in the RDF pellet impacts the pellet pores so that the water content will increase and reduce the caloric value in the RDF pellet (Sari et al., 2023).

Color pellets, either without or with the addition of PET can help the storage process in RDF. In addition, hardness can help prevent greenish, blackish, and feathery discoloration, indicating that the feed material is attacked by fungus. Mold growth is affected by moisture content during storage. The moisture content of hatchery waste pellets is relatively low with tightly closed storage conditions so there is very little possibility of reducing the caloric value (Koko et al., 2022; Sarwono et al., 2021; Suryawan, Septiariva, et al., 2022; Zahra et al., 2022). The ANOVA test is used to test for differences and test the influence of the model on the estimation of the relationship between density and hardness on the caloric value. Table 6 and Figure 2 show significant vaporization of the caloric value estimation model.

The advantages of pellets with high density are that they can reduce bulkiness, reduce storage space, reduce transportation costs, and facilitate the handling and serving of feed. However, high density will also increase feed consumption, minimize the scattered spread, and prevent decomposing of the components that make up pellets. The caloric value of RDF follows standard requirements.

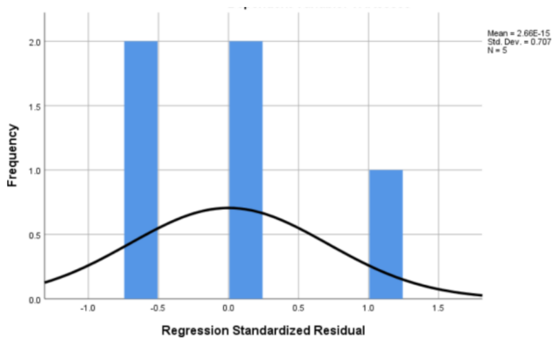

Figure 2. Frequency and regression relationship of caloric value estimation model on RDF pellet mixture of PET and biomass

CONCLUSION

The quality of the mixture of PET and biomass made into RDF pellets is physical, such as density and hardness. The estimation model for the caloric value of density and hardness increases the caloric value. Therefore, the density and hardness values in the RDF mixture show a simultaneous relationship to the heating value. The highest caloric value achieved is the use of 100% PET as pellets which can reach 5765 kcal/kg.

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