

Pelletizing of Various Municipal Solid Waste: Effect of Hardness and Density into Caloric Value

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ABSTRACT

Density and hardness are physical parameters in the manufacturing of refuse derived fuel (RDF) pellets. In making pellets, a high heating value for the combustion system is desired. This research aimed to analyze the mixture of municipal solid waste to its density and hardness and study its correlation to heating value. The variable used in this research is a mixture of paper waste and garden waste and food scraps and garden waste. The density and hardness for the mix of paper waste and garden waste were 1970.6 to 2474.8 kg/m³ and 37.8–42.8 HA, respectively. The mixture of food waste and garden waste has density and hardness of 1822 to 2276.7 kg/m³ and 17.4–37.8 HA. The correlation between density and hardness on heating values did not reach a significance of 0.05, so there was no strong relationship between density and hardness on heating values.

Keywords: density, hardness, caloric value, RDF pellets, waste.

INTRODUCTION

The utilization of RDF can be used as a substitute fuel for coal with biomass or co-firing in the cement industry (Mlonka-Mędrala et al., 2021; Sarwono et al., 2021). The high tendency of using coal causes an increase in the cost of fossil fuels (Yuliarningsih et al., 2018). The cement industry is required to have a policy of using alternative fuels that can provide efficient use of coal and have environmental benefits to reduce the CO₂ emissions, one of which is by using RDF fuel in

the form of pellets of its more uniform size (Ummatin & Arifianti, 2017). The physical quality of RDF can be used as a reference in carrying out waste processing designs such as sizes and materials suitable for use in pellet packaging. The parameters that can be used to measure the physical quality of RDF pellets are density and hardness.

The energy produced depends on the density and composition of the solid waste. About 65–80% of the energy content of organic waste can be converted into heat energy, which can be used for direct use and electricity production (Sihombing

& Darmawan, 2020). Density in RDF pellet has an essential role, because it can determine energy density in fuel volume units and is related to the handling and storage of pellets (Bantacut et al., 2013; Nunes et al., 2017). Density is the ratio of weight to volume of waste. The waste density data is used to estimate the total mass and volume of waste that must be treated. The difference in solid waste density is influenced by weather factors, geographic location, and storage time.

Apart from density, material hardness is also an essential parameter in maintaining the intact shape of an RDF pellet. Brachi et al. stated that relevant research information about oxidative atmospheres in pellets with physical properties, such as hardness, is still lacking (Brachi et al., 2019). This study aimed to determine the density and hardness characteristics of RDF pellets and their effect on heating value.

METHOD

Pelletizing processes

Pellet making is done at TPS Merdeka 2 Depok. There are three primary raw materials used in this research: food, paper, and garden waste. Food waste and paper are chopped first and then placed into a flouring machine. Garden waste is chopped first, then drying it by rotary drying, then separating with a magnet separator, and then shaving with a hammer mill. The process is continued with mixing and pellet printing. The mixing used is done by adding 10% starch. The percentage of mixed waste can be seen in Table 1.

Density analysis

Density analysis aims to determine the density of raw materials and pellets, indicating the mass and volume ratio. The tool used was an automatic density analyzer connected to a power cable Ultracyc-Quantachrome, PC, and monitor to a power source. The hydrogen gas regulator was opened to a pressure of 18 psi. The device and monitor were turned on by pressing the power button and waiting until the computer and the appliance were ready. Then, it was calibrated so that sample analysis can be carried out. Then, Quantachrome PycWeb is run and the run parameters are set. After setting it, the cells were saved and enter when filling in the run parameters into the Ultracyc 1200e tool. The sample containers

Table 1. Variations in the manufacturing of pellets in research

ID	Variation
P100	100% of paper waste
P75	75% of paper waste and 25% of garden waste
P50	50% of paper waste and 50% of garden waste
P25	25% of paper waste and 75% of garden waste
P0	100% of garden waste
F100	100% of food waste
F75	75% of food waste and 25% of garden waste
F50	50% of food waste and 50% of garden waste
F25	25% of food waste and 75% of garden waste
F0	100% of garden waste

were removed and measured using an analytical balance. The sample was entered in as much as $\frac{3}{4}$ parts of the sample container, and its weight was recorded. The container containing the sample was placed back into the cell and closed tightly. Then, the sample name and the weight of the sample that has been weighed were saved. Run-on the Quantachrome pycweb keys, and the sample were analyzed by the tool to completion. After the analysis, the results were stored in the Quantachrome pycweb report menu.

Hardness analysis

Hardness measurement used composite shore hardness (shore D). The sample of pellets used in this experiment included five pieces. Hardness measurement refers to ASTM D 2240: Durometer hardness.

Calorific value analysis

The calorific value is the total heat produced by weight from the combustion process. Calorific value can be obtained by performing a test using a bomb-based calorimeter ASTM D5865-11a.

RESULT AND DISCUSSION

Density

Density shows the ratio between mass and volume in raw materials and those already in the form of pellets. The pelletization technique is a technology used to increase mass density and increase the energy content of each volume unit. Then, pelletization also makes the size quality

more homogeneous, and the resistance of the pellets increases (Damayanti et al., 2017). Density is an essential indicator in determining the quality of pellets. High density affects the quality of the pellets the better and makes it easier to handle, store and transport because it has a homogeneous shape (Winata, 2013). A density that is too low will experience difficulties in combustion, because it affects the increase in water content (Ariefin et al., 2018). The density on RDF has its standard so that the handling, storage, and transportation processes can run properly. Countries such as Austria, America, France, and Sweden have RDF density quality standards. The standards used in these countries can be seen in Table 2.

Table 2. Standard density of RDF pellets (Bantacut et al., 2013)

Country	Bulk density standard (kg/m ³)
Austria	>1120
USA	>640
France	>1150
Sweden	>600

On the basis of Figure 1, the bulk density values for paper waste, garden waste, and food waste obtained from this study ranged from 1197-391.3 kg/m³. The value of bulk density before and after drying in direct sunlight has decreased. This is because an increase in temperature correlates with a decrease in water content, which causes the density value to decrease (Wahyono et al., 2019). Saputro et al. (Briket et al., 2012) also explained that water content significantly affects density. The water content of the raw materials before drying is very high.

If the raw material density is compared with the density of pellets, it can be seen that the density of the pellets is more significant (Figures 2 and 3). This is because the pellets are mixed with tapioca flour which can function as an adhesive when exposed to water (Wardana et al., 2015). High density in RDF pellet also occurs because of the compaction process using a pellet printer.

On the basis of Figure 2, the bulk density value in RDF pellets ranges from 1970.7 - 2247.8 kg/m³. The lowest pellet density value was in P0 pellets, while the highest was P50 pellets. The high and low-density values are influenced by the size and homogeneity of the constituents of the pellets. The pellet density value is influenced by the adhesive used to strengthen the pellet resistance. The bulk density values of the pellets were compared with the standards of several countries. The Austrian bulk density standard sets a minimum of 1120 kg/m³, the Swedish standard 600 kg/m³, the American standard at 670 kg/m³, and the French standard at 1150 kg/m³ (Bantacut et al., 2013). Overall, the bulk density value in this study has met the standards of all countries. The higher the bulk density, the denser the pellets will provide convenience in handling and storage. High bulk density value determines the quality of pellets making them stronger against crushing (Alamsyah et al., 2016).

The pellets of F0 to F100 are a mixture of food waste and garden waste, indicating a difference between the material mixed with other materials. F75 decreases in density, and Returns increases at F50 and F25. On the basis of the study results, it can be concluded that the addition of the garden waste mixture in the pellets can affect the decrease in density. The garden water content is relatively smaller so that when the pellet is pressed, the particles become easily pressed, which results in reduced

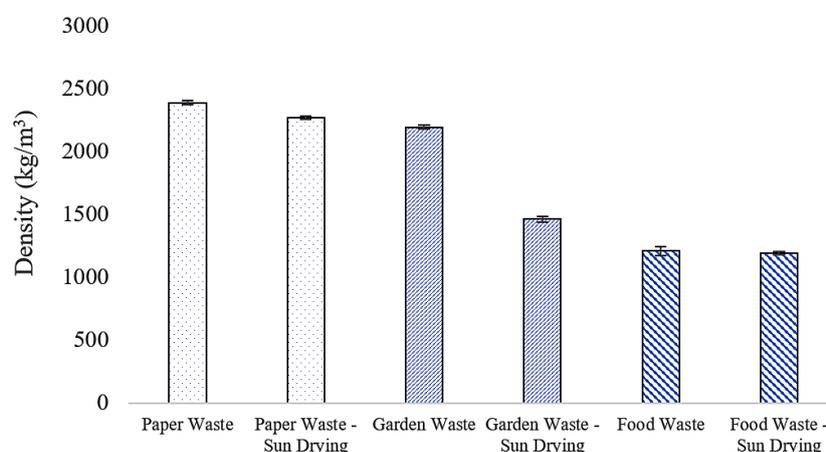


Figure 1. Results of solid waste density measurement

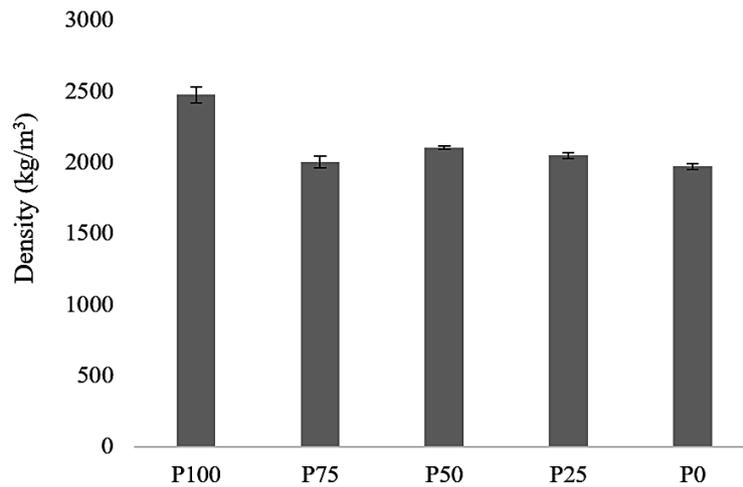


Figure 2. RDF pellet density of mixed paper waste pellets and garden waste

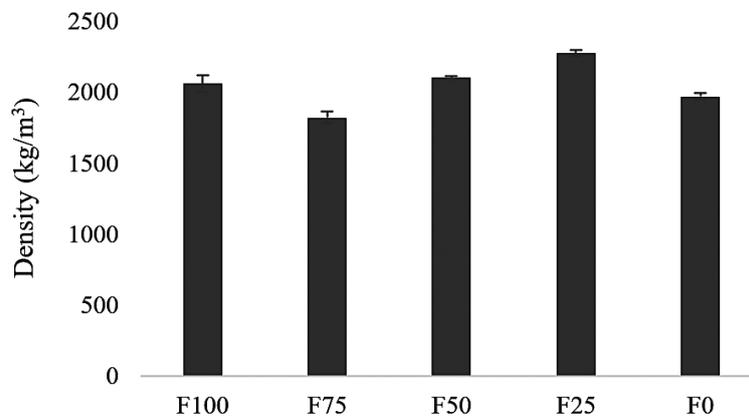


Figure 3. RDF pellet density of mixed food waste pellets and garden waste

porosity (Briket et al., 2012). Lestari et al. (Lestari et al., 2019) conducted density testing of sawdust pellets for Jabon and Ketapang wood, producing an average density value ranging from 976-1072 kg/m³. Compared to this study, the average density value was higher, which shows better pellet quality. According to Miranda et al. (Miranda et al., 2015), in general, the pellets made on a laboratory scale have a lower density value due to the limitations of the tools used. Density determines the quality of pellets, and if the density value is very low, the pellets are also of low quality because the pellets are more easily broken and crushed [17].

The value of bulk density affects decreasing the moisture content because the pressure of the pellet molding process makes the pores in the pellets smaller so that the pellet density increases. Then, the decrease in water content will affect increasing the calorific value. The tapioca adhesive can bind to each other well and fill the empty cavities, reducing the water content of pellets (Ariefin et al., 2018).

Hardness

Hardness is one of the physical parameters of RDF pellet material for resistance to deformation. Changes in the shape of the RDF pellet material can occur due to shocks in the container or the container during transportation or collisions. Hardness also shows the level of maintaining the initial purity level of the material in the manufacturing stage succession and the absence of production defects (such as the phenomenon of granular separation and appearance of impurities) in the final product (Abbas & Rasheed, 2021). The results of hardness measurements for each solid RDF pellet are seen in Figures 4 and 5. The results of mixing paper waste and garden waste look better than mixing food waste and garden waste. Food waste has a high enough water content so that the surface of food waste tends to be smoother. Meanwhile, paper and garden waste tend to have high hardness, and this is because the lignin, cellulose, and hemicellulose content in the waste are high enough so that good adhesion

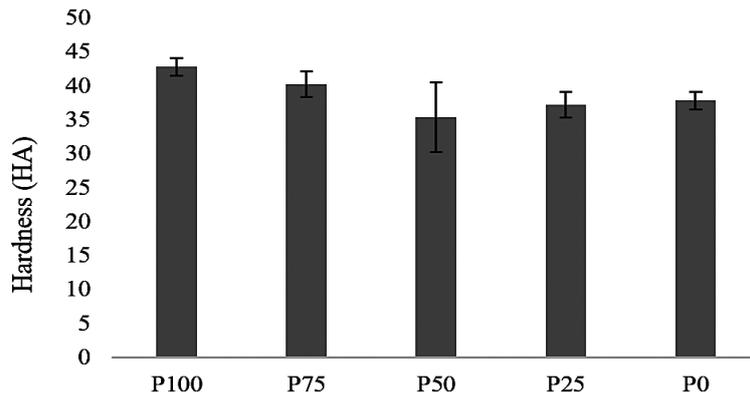


Figure 4. RDF pellet hardness of mixed paper waste pellets and garden waste

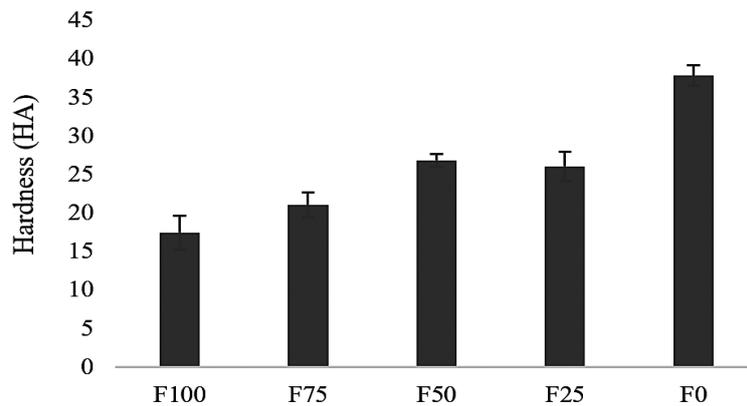


Figure 5. RDF pellet hardness of mixed food waste pellets and garden waste

occurs. Besides, the temperature of 40–70 °C used in the pellet molding tool also positively affects the hardness of the RDF pellet material.

Calorific value

Table 3 shows that the pelletizing process and litter addition to food scraps and paper have different heating values. The increase in litter composition shows a value that tends to increase in paper waste. Increasing the composition of garden waste in food waste also increases the calorific value of RDF pellets. The mixture of food scraps to garden waste will decrease the calorific value because it has 51% water content (Abdul Rashid et al., 2016).

The calorific value of the RDF pellets from food waste is higher than the RDF pellets from paper waste. The biodegradation process can increase the calorific value of food waste before the pelletizing process. Biodegradation increasing heating value can also reduce greenhouse gas emissions (Zaman et al., 2021). Greenhouse gas emissions from waste management containing degraded organic carbon

can be caused by food scraps, paper waste, and garden waste (Septiariva & Suryawan, 2021).

Statistic analysis

This analysis was conducted to find the correlation between density and hardness on heating value. A high correlation indicates the strength or degree of the linear relationship between the variable density and the calorific value or hardness and the heating value. The results of the variable correlation analysis can be seen in Figures 6 and 7.

The mixture of paper waste and garden waste tends to have a correlation relationship that increases the calorific value if the density and hardness are reduced. In contrast to the mixture of paper waste and garden waste, the mixture of food waste and garden waste increases the caloric value when the density and hardness increase. Because correlation value of each variable do not reach a significance of 0.05, definite conclusions cannot be drawn between these variables. Thus, further research is needed to find a definite value in determining the physical properties of RDF pellets.

Table 3. Calorific value for each variation of RDF pellet making

Pellet ID	Caloric value (kcal/kg)	Pellet ID	Caloric value (kcal/kg)
P100	3121.9	F100	4115.0
P75	3884.2	F75	4186.0
P50	4042.1	F50	4671.0
P25	4365.2	F25	4879.0
P0	4532.1	F0	4532.1

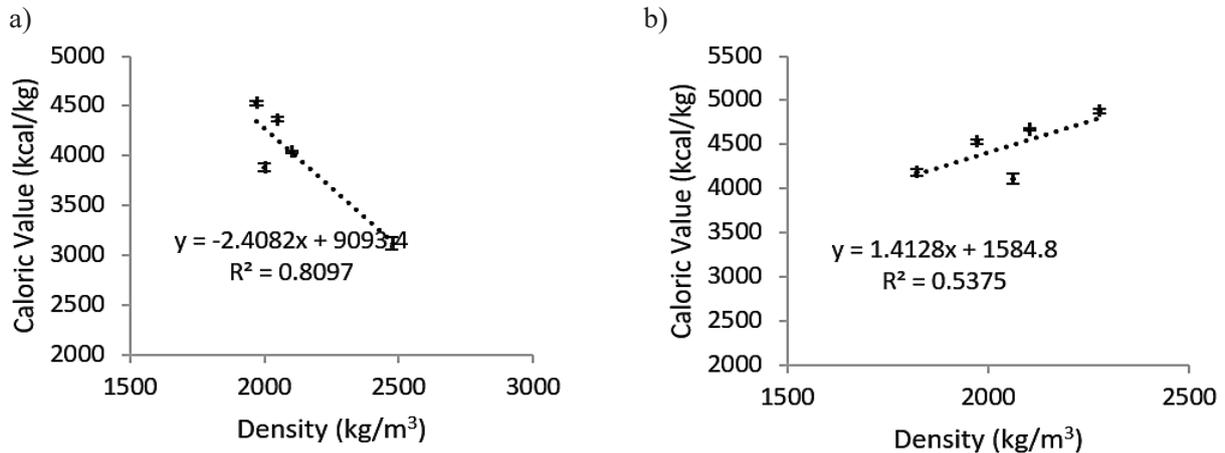


Figure 6. Correlation between density and heating value for each variation of RDF pellet making: mixture of paper waste and garden waste (a), mixture of food waste and garden waste (b)

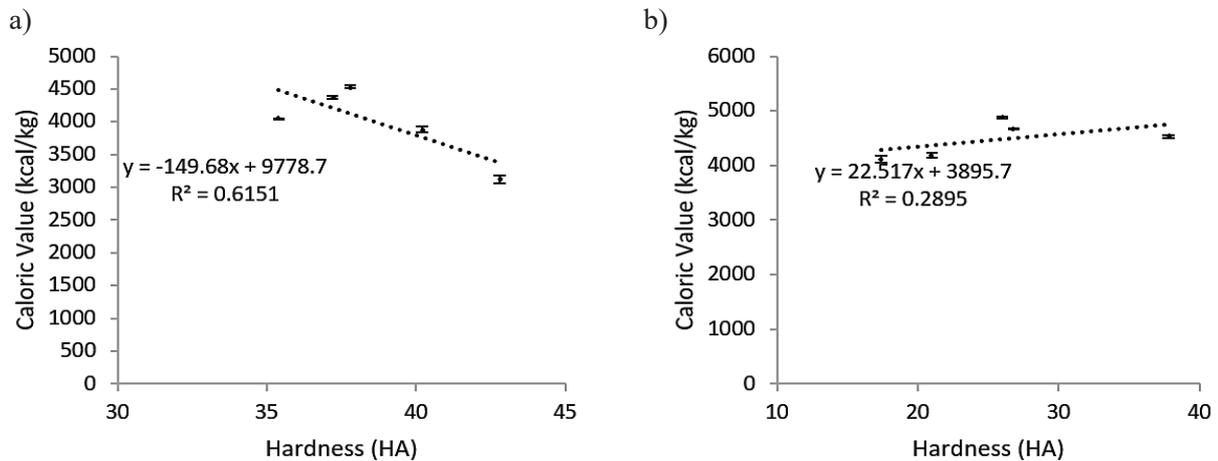


Figure 7. Correlation between hardness and calorific value for each variation of RDF pellet making: mixture of paper waste and garden waste (a), mixture of food waste and garden waste (b)

CONCLUSIONS

The density and hardness of mixed RDF pellets from paper waste and garden waste have the values of 1970.6 to 2474.8 kg/m³ and 37.8–42.8 HA, which tend to increase with the amount of paper waste. Meanwhile, density and hardness of mixed RDF pellets from food waste and garden waste have values from 1822 to 2276.7 kg/m³ and 17.4–37.8 HA. The correlation between the density and hardness variables does not show a significance

value of 0.05 on the calorific value. Hence, it does not reinforce the statement that density and hardness have an increased calorific value relationship.

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