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Influence of Die Temperature on Unit Density and Calorific Value of Municipal Solid Waste Pellets

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ABSTRACT

The process of waste to energy can solve the problem of waste and produce energy as a by-product. The waste can be used as a raw material in pelletization process which then used as a fuel in the thermal processing technology. In the pelletization process there are operational variables that influence the characteristics and quality of the pellets. Variation of waste composition (food waste, garden waste, plastic and paper), die temperature (ambient, 60°C, 80°C, 100°C, and 150°C) and particle size (mixed, <0.5 mm, and 0.5-5 mm) are done in this study. The waste was processed through natural drying, crushing, and pelletizing using the single pellet press method. The pellet pressure and dimensions of the pellet mold are fixed at 288 MPa and 6 mm in diameter. Density measured by verniercaliper and precision analytical balance. Calorific value measured by bomb calorimeter PARR 6400. The results showed that there was a simultaneous influence of die temperature on the density and calorific value of the pellet.

Keywords: *Die Temperature, Pelletization, Municipal Solid Waste, Single Pellet Press*

1. INTRODUCTION

The process of waste to energy can solve the problem of waste and produce energy as a by-product. Generally, the largest composition of municipal solid waste consist of food waste, garden waste, plastic, and paper, which have a range of combustion heat value up to 30 MJ/kg [1]. Therefore, the energy contained in municipal solid waste can be processed into alternative fuels.

Based on American Standard Testing and Material (ASTM) definition [2], the utilization of municipal solid waste for production of energy or Refuse Derived Fuel (RDF) classified into 7 type. RDF-1 is waste used as a fuel in as-discarded form. RDF-2 is waste processed to coarse particle size with or without ferrous metal separation. RDF-3 is shredded fuel derived from municipal solid waste that has been processed to remove metal, glass, and other inorganics and has a particle size such that 95% weight passes through a 2-inch square mesh screen. RDF-4 is combustible waste processed into powder form with 95% weight passing a 10 mesh screen. RDF-5 is combustible waste densified (compressed) into the form of pellets, slugs, cubettes or briquettes. RDF-6 is combustible waste processed into liquids fuel. RDF-7 is combustible waste processed into gaseous fuel.

The pelletization process produces pellets which are included in the RDF-5. In this process, there are variables that can affect the properties of the pellets produced which include moisture content of raw material, particle size, presence of binders, and machine parameters such as pressure gap, die diameter, channel length, die speed, etc. [3].

Research related to various of raw materials and specification parameters have been carried out. Demirbas (1999) and Yaman et al. (2000) examined the types of paper waste materials with variable particle size and the addition of organic wheat material [4] and olive pulp [5]. Chiemchaisri et.al., (2010) examined the types of plastic waste materials with the addition of binding agents [6]. Prasityousil et al. (2013), Srivastava et al. (2014) and Ahmad et al. (2018) examined the types of compost waste material [7], vegetable waste [8], and banana plant waste [9]. Nguyen et al. (2015)examined the variations in die temperature parameters, raw material moisture content, operational pressure, and particle size with raw materials of sugar marple wood chips [10]. The same research was carried out for each different raw materials, such as Said et al. (2015) with raw materials of straw [11], Ramezanzade et.al., (2018) with raw materials for residual pistachio nuts [12].

Although some researchers investigated various of raw materials and parameter specifications for making pellets, municipal solid waste raw materials especially that is simulated to real conditions have not been carried out. Thus, the main objective of the present study is to investigate influence of die temperature as parameter specification on unit density and calorific values as quality of pellet for municipal solid waste simulated composition based on waste composition collected from Bantargebang landfill which the landfill is dedicated for Jakarta City, Indonesia.

2. MATERIAL AND METHODS

2.1. Sampling

Samples were taken simultaneously in January 2019. Samples of food waste, plastic, and paper were taken from residential areas while garden waste samples were taken from the yield of sweeping the garden area. The type of food waste is limited by food scraps containing leftover food ingredients such as potato skin, onion skin, fruit peel, fruit stalks, egg shells, corn cobs, and pieces of vegetables that have withered, garden waste only contains a sweep of the Cempedak trees (*Artocarpus integer*) area at University of Indonesia, plastic waste only contains multilayer plastic pieces, such as snack packages, packaging beverage labels, and candy wrappers, and paper waste only contains pieces of paper bills, shopping receipts, leaflets and brochures.

(a) (b) (c) (d)

Figure 1 Sample material (a) Food Waste, (b) Garden Waste, (c) Plastic, (d)Paper

The composition of waste entering Bantargebang landfill in 2017 consisted of 52.91% food waste, 6.10% garden waste, 14.85% plastic, 7.49% paper, 3.56% textile, 1.78% rubber, 1,94% metal, 2.60% glass, 8.76% others. Furthermore, the sample for this study followes the data from the composition of the landfill, but limited only on the ratio of food waste, garden waste, plastic, and paper. There are two types of composition ratios, namely the ratio of initial conditions (composition A) and alternative conditions. The alternative composition assumed that there is a process of reducing organic waste (food waste and garden waste) with the composting process so that the waste disposed to landfill is reduced by 20% (composition B).

Table 1. Composition ratio of sample

Composition	Ratio A	Ratio B
Food Waste	70.1	66.5
Garden Waste	8.1	7.7
Plastic	11.9	14.1
Paper	9.9	11.8

2.2. Preparation of Sample

Sample pre-treatment used the drying and grinding process. Samples were dried naturally (sun drying) for 14 days for food waste and 1-3 days for other wastes. After the raw material was dry enough, the sample was grinded. Grinding was carried out in two stages, where the first stage of grinding for each sample component and the second stage for the combined sample component. The first stage of grinding used an electric blender (food waste and garden waste) and a paper crusher with a maximum yield size of 5 mm (plastic and paper) while the second stage of grinding used a crusher machine with high speed rotation. The sample milled was sifted with a 30 mesh sieve (0.5mm) so that obtained variations in particle size consist of initial size (mixed), <30 mesh (<0.5mm) and>30 mesh (0.5-5mm).

2.3. Pelletizing Process

Peletization used a single pellet press method consisting of pellet die and hydraulic press. This method refers to previous studies[3], [10], [13]–[15]. The cylindrical pellet die with a diameter of 6 mm is made of hardened steel, equipped with a heating element module and calibrated thermocouple. Compression of raw materials was carried out by a hydraulic press at a pressure of 288 MPa for 150 seconds.Die temperature varied from ambient temperature, 60°C, 80°C, 100°C, and 150°C.

2.4. Laboratory Testing

The pellets that have been produced are then tested in the laboratory to determine the pellet properties.

2.4.1. Unit Density.

Unit density testing is expressed as a ratio of weight per unit volume of pellet units. The testing method refers to previous studies [11], [16], [17]. Density testing is divided into three categories, namely unit density, bulk density, and tapped density. Because of the limited production of pellets, in studies with single pellet press only tested the unit density. Testing equipment includes calipers and analytical scales. Tests were carried out at the Universitas Indonesia Faculty of Engineering Gasification Laboratory and carried out right after the pellet was formed.

2.4.2. Calorific Value.

Tests of calorific values are expressed in gross calorific value, namely the amount of heat generated from combustion of a number of fuels at constant volume conditions, in the oxygen bomb calorimeter under specific conditions. The test method for calorific value refers to ASTM E 711-87 about the Standard Test Method for Gross Calorific Value of Refuse Derived Fuel by the Bomb Calorimeter. Tests were carried out at the Analytical Chemistry Laboratory of the Animal Research Center (Balitnak) using bomb calorimeter type PARR 6400.

3. RESULTS AND DISCUSSIONS

3.1. Pellet Properties

Table 2 shows the result of the experiments. Pelletizing was held in March 2019 with total number of pellet is 30 pellets consist of 5 variations in die temperature (ambient, 60°C, 80°C, 100°C, and 150°C), 3 variations in particle size (mixed sizes, sizes <0.5 mm and size 0.5-5mm), and 2 variations in waste composition ratio (A and B).

Table 1. Pellet properties result

Exp. No.	Composition	Particle Size [mm]	Die Temperature [°C]	Unit Density [kg/m³]	Calorific Value [kcal/kg]
1	A	mixed	30	912	3195
2	A	<0.5	30	1346	1499
3	A	0.5-5	30	646	4577
4	A	mixed	60	785	2921
5	A	<0.5	60	1370	1361
6	A	0.5-5	60	810	4569
7	A	mixed	80	1073	3491
8	A	<0.5	80	1476	1679
9	A	0.5-5	80	972	4775
10	A	mixed	100	1124	3180
11	A	<0.5	100	1337	1982
12	A	0.5-5	100	948	5093
13	A	mixed	150	1227	3145
14	A	<0.5	150	1457	1776
15	A	0.5-5	150	987	5828
16	B	mixed	30	843	3009
17	B	<0.5	30	1378	1844
18	B	0.5-5	30	795	3916
19	B	mixed	60	1014	3089
20	B	<0.5	60	1470	1611
21	B	0.5-5	60	936	4171
22	B	mixed	80	1031	2552
23	B	<0.5	80	1414	2252
24	B	0.5-5	80	885	4106
25	B	mixed	100	1076	3806

26	B	<0.5	100	1466	1408
27	B	0.5-5	100	983	4445
28	B	mixed	150	1158	3910
29	B	<0.5	150	1488	1915
30	B	0.5-5	150	950	4102

In experiments, ambient temperature shows the die temperature is 30°C. Unit density of pellet MSW ranging from 646-1.488 kg/m3. The smallest unit density is from municipal solid waste with particle size 0,5-5 mm, and the biggest one is from particle size <0,5 mm. Small particle size can fill more gaps compared to large particle size. This makes the density of smaller particle size has the biggest density value. This condition applies to composition A and B. The difference in unit density in each composition ratio is not much different.

Calorific value of pellet MSW ranging from 1.361-5.828 kcal/kg. The smallest and the biggest calorific value are from composition A. Where the smallest at die temperature 60°C withparticle size <0,5 mm and the biggest at die temperature 150°C with particle size 0,5-5 mm.

3.2. Effect of Die Temperature on Unit Density

As shown in Figure 2, unit density of the pellets increases with increasing die temperature. However, the increase in unit density values at higher temperatures is getting smaller. This condition shows that there is an optimum die temperature to provide high unit density.

At low die temperature, the protein content in the biomass begins to act as a binding agent [3] even waste paper can be plays the role of a binder [4], [18]. Food waste and garden waste have high protein in the form of lignocellulosic fiber which will increase pellet density. However, at higher temperatures (> 130°C), the presence of lignocellulose fibers reduces the modulus of elasticity of biomass particles and makes them more flexible or softer. This results an empty space between and inside the particles which can reduce pellet density [3]. So that unit density tends to start to decrease.

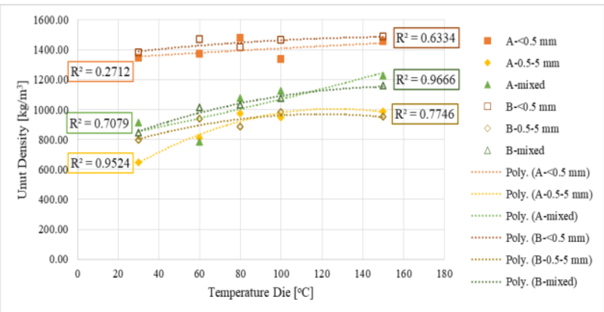

Figure 2 Effect of die temperature on unit density for MSW biomass materials

At particle size <0.5mm, unit density does not show a significant change in die temperature. This is because small particle sizes, which contain natural binder, interlocking between particles more stronger than the big particle size. The die temperature does not effect significantly due to the small particles have been fill the gap between particles[13].So that the increase in die temperature does not make a significant change in unit density.

3.3. Effect of Die Temperature on Calorific Value

As shown in Figure 3, there are several trends between die temperature and calorific value. The first trend is increasing in composition A particle size 0,5-5 mm and composition B particle size mixed, the second trend is likely to decrease in composition A particle size mixed and composition B particle size 0,5-5 mm, and the third trend tends to be stable in composition A and B particle size <0,5 mm.

In the first and second trends the change in trends starts at a temperature range of 80 -100 C. This is due to an increase in temperature changes in the chemical components of the sample material to form lignocellulose fibers. The amount of lignocellulose will have an impact on the calorific value. In the first trend the amount of material that forms lignocellulose is higher than the second trend. So that the first trend experienced a significant increase in the calorific value.

In the third trend has the lowest calorific value. Due to the minimum chemical component that can be lignocellulose form in both of composition A and B.

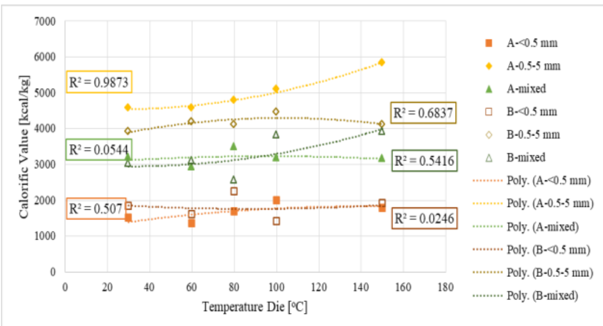

Figure 3 Effect of die temperature on calorific value for MSW biomass materials

3.4. Correlation of Unit Density and Calorific Value on MSW Pellets

Figure 4 shows the correlation between unit density and calorific value based on experimental data. The results show that there are groupings of data at particle size and the same trend for die temperature at each particle size groups.

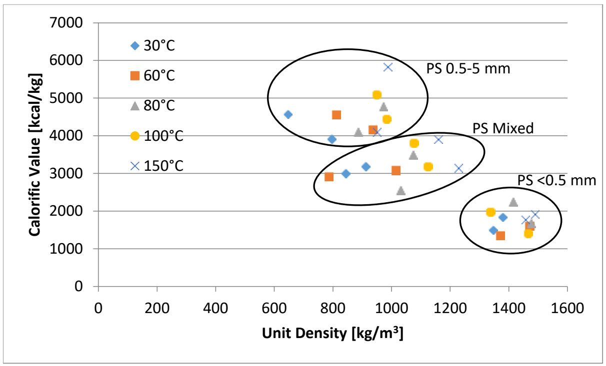

Figure 4 Relation between Pellet Properties (Calorific Value/Unit Density)

The groups with particle size <0.5 mm have the highest unit density value but the lowest calorific value and the groups with 0.5-5 mm particle size have the highest calorific value but the lowest unit density value. The thing that affects these two parameters is the presence of water in the particles of pellet raw material. In the process of pelletization, water evaporation occurs especially at higher temperatures [19]. At low unit density value, more water evaporate through gap between particles so that the calorific value more higher, whereas at high unit density value, water is trapped between particles so that the calorific value becomes lower.

In each particle size group, increasing temperature die results increasing in unit density and calorific value. Difference in increase of unit density value for particle size respectively <0.5 mm, mixed, and 0.5-5 mm reached 10.67%, 43.18% and 38.26% of the average value of the unit density for each group of data. While the difference in the increase in calorific value for particle size in a row <0.5 mm, mixed, and 0.5-5 mm reached 51.42%, 42.05%, and 41.95% of the average calorific value of each group data.

4. CONCLUSION

Municipal solid waste can be formed directly into pellets. The die temperature at the time of pelletization process affects the quality of the pellet on the unit density and the calorific value. The higher die temperature results higher calorific value and unit density. Particle size variables also affect the quality of the pellets produced.

It is necessary to develop a methodology or simulation for making large scale municipal solid waste pellets by considering the fluctuations in existing waste. Apart from that the combustion characteristics of the pellets produced will still be further investigated.

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