Municipal Solid Waste to Energy: Palletization of Paper and Garden Waste into Refuse Derived Fuel

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ABSTRACT

The purpose of this research was to process a mixture of paper waste and garden waste based on material flow analysis and to analyze its parameters based on water content, ash content, heating value, along with Thermogravimetry Analysis (TGA)/Derivative Thermogravimetry (DTG). The garden waste treatment process consists of shredding, drying with a rotary dryer, separator, and then shaving with a hammer mill. Paper waste only needs a shredder process. Then, the mixing process and pelletizing of paper waste as well as garden waste are carried out according to the variation (w/w) 100% paper (K100), 75% paper (K75), 50% paper (K50), 25% paper (K25), and 100% garden waste (K0). The water content ranged from 5.8 to 15.25%. From K0 to K100 samples, the ash content increased from 4.54 to 9.85%. A correlation of 0.9047 was found from samples K0 to K100. There was a correlation between increasing calorific value along with the mixture with paper waste. The caloric value in K0 to K100 increased from 13.11 to 19.03 MJ/kg. The TGA/DTG analysis reduced mass due to water evaporation, devolatilization, and carbonization processes.

Keywords: waste to energy, pelletizing, garden waste, paper waste.

INTRODUCTION

Municipal solid waste (MSW) is a severe problem faced by cities in Indonesia, including Depok City [1]. Depok City is geographically adjacent to Jakarta and Bogor, so it is a very strategic area to support economic activity [2]. Depok City is included in a metropolitan city category among 14 other metropolitan cities with a high population density. In 2019, the population in Depok City was 2,406,826 people [3]. A larger population size correlates with a higher amount of waste [4]. On the basis of the data from the Depok City Environment and Sanitation Service in 2019, the amount of waste generation in Depok City was 1070 tons/day. The amount of waste managed by the City of Depok is 57.2% through waste sorting, composting, and dumping it to the

Cipayung Final Processing Site (TPA). The land area of the Cipayung TPA is currently experiencing a critical period along with the increase in waste generation, so that the volume of waste in the TPA has exceeded its capacity (overload) [5]. Depok has launched a waste bank program and a Waste Management Unit (UPS) to encourage people to engage in waste sorting activities. The sorting activity carried out for organic waste, such as food waste, involves using a closed bucket container then collected at the collection point by officers every two days and then processed into compost at the UPS. Inorganic waste such as paper, cardboard, glass, plastic bottles, cans, metal, glass bottles, and others will be deposited into a waste bank [6].

The Depok City Government is interested in effective and efficient waste processing by converting waste into Refuse Derived Fuel (RDF). RDF is a waste processing technology through a series of processes to achieve high calorific value, reaching 3000 kcal/kg, a low water content below 20%, and more homogeneous size, making it more manageable in terms of storage and transportation [7]. In 2018, the Ministry of Public Works and Public Housing (PUPR) and the Depok City Government built the Merdeka 3 Waste Processing Site (TPSS) as a pilot project for waste to energy in the form of RDF pellets. The TPSS is still in the testing phase; hence, the waste that is processed is still limited to wood twigs and dry leaves, known as garden waste. The pellets made from garden waste can become renewable energy and are currently being used as fuel in tofu factories and the stove and gasifier fuel to operate electric diesel at TPSS Merdeka 3. TPSS Merdeka 3 has a plan to produce pellets using other waste raw materials, but there has not been a study on different waste compositions' characteristics. TPSS Merdeka 3 recommends no plastic waste content in RDF pellets because it is against Depok City's environmental licensing. After all, plastics contain dangerous substances, namely carbon monoxide and dioxins [8]. Food waste includes a very high-water content, so the potential for decay will affect the quality of RDF pellets [9, 10].

On the basis of the technology of processing waste into RDF pellets that already exists in TPSS Merdeka 3, paper waste was selected in this study to be processed into RDF pellets because paper waste has not been utilized. Paper waste has similar characteristics to garden waste, because it is made of wood fiber; this gives the fuel a good density quality. Paper has a 3024 kcal/kg heating value that can be used as RDF pellets [11]. The paper waste content in RDF pellets will increase the strength of pellet structure and make the pellets more durable [12].

Important parameters that determine the characteristics and quality of RDF include water content, ash content, heating value, and chemical composition [13, 14]. Other important parameters are Thermogravimetry Analysis (TGA)/Derivative Thermogravimetry (DTG) and density; TGA/DTG functions to determine the thermal stability of pellets. Therefore, paper waste and garden waste potential as RDF raw materials need to be reviewed from their characteristics and quality based on water content, ash content, calorific value, density, chemical composition, and TGA/DTG. The purpose of this study was to analyze the material flow and characteristics of pellets from variations in the composition of paper waste and garden waste and their potential to produce the best quality RDF pellets.

EXPERIMENTAL

Data collection

Data collection was divided into primary data and secondary data. Primary data was obtained from taking raw material samples, namely paper waste and garden waste, making RDF pellets from variations in paper waste and garden waste composition. The RDF pellet was tested in the laboratory, including water content, heating value, density, and TGA/DTG of RDF. The RDF pellets produced were tested in the laboratory, including density, water content, ash content, calorific value, and TGA/DTG.

The data were analyzed and processed to obtain a correlation between the five RDF pellets made of raw material from variations of waste with several parameters: the calorific value, water content, ash content, and TGA/DTG. The analysis of the quality of RDF pellets was compared with RDF standards regarding water content parameters, ash, and calorific value.

The method used to analyze the water and ash content is the American Standard Test Method (ASTM) for Residual Water and Ash in a Refuse-Derived Fuel Analysis Sample E790-87 (2004) and E830-87 (2004), respectively. Calorific value

analysis was performed to describe the energy content of a material. The calorific value calculation was done using a bomb calorimeter. The method used for calorific value analysis is the American Standard Test Method for Gross Calorific Value D5865-11a. TGA/DTG analysis is a thermal analysis technique that measures mass changes as a temperature and time function. The combustion characteristics analysis was carried out using the STD Q-600 instrument connected via a computer to obtain the results directly.

Pellet making

The raw material used in this study is a variation of paper waste and garden waste composition, carried out by the pelletization process to become fuel in the form of pellets. After production, the pellets are stored using an airtight container to prevent their contact with air so that the quality of pellets is maintained because they will be tested in the laboratory.

Data processing and analysis

The data processing and analysis stages were carried out after all primary and secondary data have been collected. The laboratory test results were then analyzed statistically. RDF pellets were compared with RDF standards, so that it can be seen which variations of the waste have the best quality as RDF raw materials.

RESULTS AND DISCUSSION

Pelletizing

Pellets are generally a raw material that goes through a compaction process by a pellet molding machine to have a denser and more substantial structure than raw materials that have not been pelleted. The advantages of fuel in pellets can increase the calorific value and density of the

pellets. Besides, the pellets have a more homogeneous size and uniformity aspect so that the transfer/transportation process is more accessible and does not require large storage space [15]. The pellets were made at TPSS Merdeka 3, Sukmajaya District, Depok City, West Java.

Table 1 compares the percentages used in manufacturing of pellets from variations of paper waste and garden waste. Making pellets uses raw materials from variations of paper waste and garden waste with 25% interval variations with a total mass of 2000 grams and 200 grams of starch. The use of raw material variations for making pellets at 25% intervals was carried out. The making of pellets from variations in the composition of the waste at this interval was carried out to determine the composition variation with the best quality to determine the quality of RDF pellets. In the manufacturing of pellets, an adhesive material is needed to bind to each other when given pressure and aim to increase the bond between particles. Starch is the adhesive material most often used pellet manufacturing, because it is relatively cheap and easy to obtain, besides it is not easily broken, has high adhesive strength, and good ignition properties [16]. According to the research by Damayanti et al. [17] the use of 10% tapioca starch adhesive has a good density, because it produces strong pellets and is not easily cracked. The addition of more than 10% adhesive can reduce the density so that the level of pellet homogeneity is decreased. The pellets produced without adhesive have rougher surface, so that it is easily crushed when pressed during the printing of the pellets. Therefore adhesive is needed in the manufacturing of pellets [17].

Figure 1 shows the pellet-making process at TPSS Merdeka 3, which includes chopping or reducing raw materials, drying garden waste in rotary dryers, shining in hammer mill machines, pelleting using an 8 mm pellet printing machine, and sun drying. Molding is pressing and compacting materials through machine holes using a mechanical process that involves heat and pressure.

Table 1. Variations of waste used as raw material for RDF pellets

Paper waste	Garden waste	Tapioca starch (10%)	ID
100% (2000 gram)	0% (0 gram)	200 gram	K100
75% (1750 gram)	25% (250 gram)	200 gram	K75
50% (1000 gram)	50% (1000 gram)	200 gram	K50
25% (250 gram)	75% (1750 gram)	200 gram	K25
0% (0 gram)	100% (2000 gram)	200 gram	K0

Figure 1. The process of making pellets with a variety of paper waste and garden waste

When forming solid pellets, the optimum temperature in the machine is around 60–80°C. If the engine temperature is above 80°C, it will damage the lignin bond, while temperatures below 60°C will make it difficult to form pellets [18]. After the pellet molding process is complete, there is an increase in temperature and water content in the pellets, so it is necessary to cool down at room temperature than dry in an open area in the sun. Drying under direct sunlight aims to make the pellets denser, not easily broken, and reduce the water content to avoid mold growth [19]. After going through the drying process, the pellet fuel is stored using an airtight container to minimize the increase in water content.

Figure 2. Pellet results from various variations; (a) K100 pellets, (b) K75 pellets, (c) K50 pellets, (d) K25 paper pellets, (e) K0 pellets

Figure 2 shows the pellets from paper waste variations with garden waste, which have a diameter of ± 8 mm. The 100% Garden waste pellets have a dark color because they come from hardwood/hardwood. Hardwood is better to use because it is denser, has lower water content, and burn resistance is greater than in softwood [15]. Pellets with 8 mm can be applied as stove fuel for household or industrial scale and power plants [20]. At the time of making K0 pellets and K50 pellets, a blockage occurred in the machine, this was due to the condition of the machine, wear out quickly, so it was necessary to add water to the pellet mixture and also to the pellet molding machine to facilitate the pellet formation process.

The form of the pellets produced from paper waste and garden waste in this study has a solid shape and does not break easily, yielding good quality pellets. Water should not be added in excessive quantity because it will cause very high pressure on the die to increase [21]. Then, the resulting pellets become soft and very easily broken apart. As a result, the pellet surface is not smooth and is not cylindrical. Conversely, if there is not enough water, the printer cannot apply pressure properly.

Water and ash content

The analysis of water content and ash content is used to determine the amount of water and ash content of each sample, and low water content will result in good fuel quality. The water content and ash content data is shown in Table 2. The water content in the pellets from each variation of waste has values. The results showed that the water content in the pellets ranged from 5.8–15.5%. The water content of the K-100 pellets was 10.09%, the K75 pellets were 5.8%, the K50 pellets were 9.46%, the K25 pellets were 8.46%, and the K0 pellets were 15.25%. The lowest water content value was found in the K75 pellets, while the K0 pellets have the highest water content. The five RDF pellets in this study have met

the RDF standards from Italy [22]. Only the K75 pellets did not meet the British standards.

The high and low water content of the pellets in this study can be influenced by the type of raw material used and can also be affected by water in the pellet-making process. This shows that 25% of garden waste and paper waste affect the water content value, but the water content obtained shows the results are not much different. Paper waste accumulation shows a decrease in water content, because it is part of the biomass with water absorption properties [23]. The characteristics of the type of raw material for waste also affect the water content of pellets. The water content of paper waste is 10.02% lower than that of garden waste which equals 20% [24]. Garden waste also naturally occurring lignocellulosic material that is hygroscopic. The garden waste can absorb water from the air and release water vapor [25].

Water content is an important parameter that affects heating value, combustion efficiency, ease of ignition, and smoke produced during combustion [26]. The high-water content will reduce the combustion efficiency because the water content of pellets will absorb heat to evaporate water, reducing the calorific value. The combustion temperature will be low due to loss of heating value or heat due to incomplete combustion, which will cause smoke. Meanwhile, a low water content value will increase the combustion efficiency, and less smoke will be generated because the heat energy released will be used to heat the fuel [27].

When making the K50 pellets and K0 pellets, there were problems with the pelletizing machine. Due to the machine condition, which was easily worn, it was necessary to add water to the pelletizer machine and the pellet mixture so that the printing machine could operate again. This addition of water will affect the characteristics of the pellets. The addition of water functions as a lubricant in the pellet press machine. Moreover, water causes the pellet mixture ingredients to become soft, so that the pellets can come out through the molding quickly. The type of pelletizer used is a flat die; the disadvantage is that the

Table 2. Water content and ash content in each variation of the pellets used

Variation	Water content (%)	Ash content (%)	Italia standard [22]	England standard [22]
K100	10.09	9.85	Water content: Maximum 25% Ash content: Maximum 20%	Water content: Maximum 7-28% Ash content: Maximum 12%
K75	5.8	7.71		
K50	9.42	7.1		
K25	8.46	6.94		

machine wears out quickly, so that maintenance and cleaning must be done frequently, while the advantages are that it is cheaper and is commonly used on a small scale. Although there were problems with the machine that required water addition to the pellet mixture, the overall water content did not exceed the standard. The high-water content affects pellet damage and makes them susceptible to attack by fungi so that the pellets do not last long. The research by Al Qadry et al. [28] concerned also pellets from other raw materials, namely from a mixture of palm oil shells and wood powder, producing a 7.6%–11% water content value. Compared to that study, water content value in this study did not differ much from K-75, K50, and K-0, but higher than the K-25 pellets and lower than the K-0 pellets.

The ash content value results in each waste composition variation having different values; the study results show that the ash content value ranges from 4.54–9.85%. The ash content in the K-100 pellets was 9.85%, the K75 pellets were 7.71%, the K50 pellets were 7.1%, the K25 pellets were 6.94%, and the pellets with 100% garden waste – 4.54%. The highest ash content was found in the K100 pellets, while the lowest ash content was observed in the K0 pellets.

The ash content indicates the amount of ash or residue that remains when the combustion is complete. The ash content is formed from mineral substances such as nitrogen, phosphorus, magnesium, and silica in fuel [29]. The ash content corresponds to the impurities that can no longer burn during the combustion process or no longer have carbon elements [30]. The ash content affects the quality of the fuel, namely the calorific value. High ash content can reduce the combustion performance and cause scale in the combustion furnace, which results in corrosion in the engine [31].

The ash content results showed that the five RDF pellets met the Italian and English standards [22]. The higher the addition of garden waste, the lower the ash content produced. The ash content of the paper waste is more significant, namely 11.55%, and the ash content of garden waste is lower, i.e. which is 7.15% [32]. The garden waste has high hemicellulose, cellulose, and lignin content. The ash in garden waste is an ash-forming mineral left from burnt organic compounds. The lower the ash content value, the better the calorific value or, the higher it is. High ash content indicates a large amount of mineral content, causing the efficiency and speed of combustion to decrease because the energy used for heating is more absorbed by minerals. The research by Putri and Sukandar has also made pellets from other raw materials, namely from variations in sludge and composition of oil palm bunches, which produce the ash content values ranging from 13.05% to 24.3% [33].

Calorific value

Calorific value analysis is carried out to determine the fuel energy, defined as the amount of heat produced through a complete combustion reaction [34]. The value testing data for variations in research can be seen in Figure 3. It can
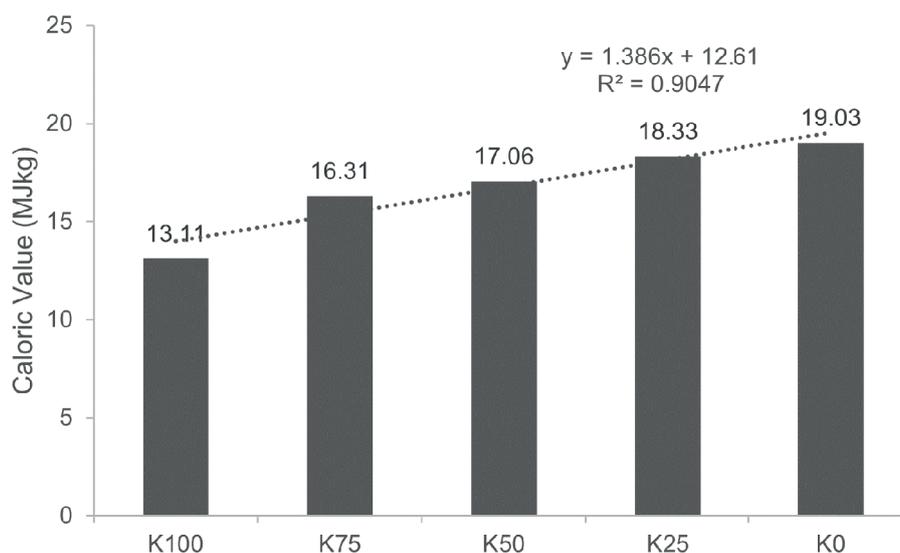
Figure 3. Correlation of caloric value (MJ/kg) with each variation of the pellets used

be seen that the correlation of the addition of garden waste and paper; R^2 is 0.9047; this shows that the increase in the percentage of garden waste will increase the calorific value. Meanwhile, more paper waste content will reduce the calorific value. Pasek et al. [32] also obtained a similar result: the calorific value of garden waste shows a higher value than paper waste. Garden waste is biomass that has high cellulose, hemicellulose, and lignin content. The lignin content can be a natural adhesive, increasing pellet density and calorific value [35]. Paper waste is also made of wood components, so that it has almost the same characteristics as wood which contains cellulose, hemicellulose, and lignin fibers. Still, the lignin content of paper is not as high as that of garden waste [23]. The lignin content in material also affects the calorific value where lignin will be activated and function optimally as an adhesive [36]. The lignin content will also affect the density of the pellets. The higher the pellet density, the higher the calorific value is. The high density will make the pores fill with each other so that there are no voids that increase the water content [15]. RDF from different raw materials, namely from leaf and paper waste variations, produced a calorific value of 12.9–13.97 MJ/kg [37].

Thermogravimetric analysis / derivative thermogravimetry

Figure 4 shows the TGA/DTG graph results from a combination of all RDF pellets using the OriginLab2020 software, aiming to make it easier to read curves and find out the differences in the TGA/DTG curves in each sample. In the TGA/DTG curve, there are 3 stage areas, and the first stage is mass loss due to water evaporation which occurs at the initial temperature of combustion, which is at a temperature lower than 100°C [38]. The second stage occurs the devolatilization process or evaporation of compounds into gas depending on the sample used and is characterized by a drastic decrease in mass [38]. The third stage is the carbonization process characterized by a reduction in mass which tends to be stable.

Thermal analysis analyzes a sample in a hot and rate-controlled environment by looking at an increasing temperature on mass changes during the combustion process. The TGA curve is a function of mass reduction with increasing temperature. The DTG curve is the decrease of the TGA or mass reduction rate concerning temperature. The curve of the DTG shows the peaks that occur during the devolatilization process [39]. The TGA/DTG analysis is usually applied to determine the material characteristics, temperature reduction, and components of inorganic and organic compounds. The TGA/DTG test was carried out in a temperature range of 30°C to 800°C with a heating rate of 10°C/minute. The gas used to test the TGA/DTG is an inert gas such as nitrogen with a 50 ml/minute flow rate. The sample is placed in alumina, then in a thermocouple or electric heater to measure temperature and connected to a computer to control the programmed to produce a temperature versus mass TGA/DTG graph. The graph in the TGA analysis is shown as a function of mass reduction with increasing temperature.

Garden waste is biomass consisting of three main components, namely hemicellulose, cellulose, and lignin. The mass in biomass will decrease if there is an increase in temperature because heat will decompose the chemical compounds of biomass into gaseous compounds [18]. The decomposed biomass is divided into three stages: the first stage, the sample loses mass due to water evaporation in the sample. The second stage is related to the devolatilization of hemicellulose, cellulose, and lignin compounds. The third stage relates to thermal stability, namely, the mass has begun to stabilize, or there is no more mass change [40].

Thermogravimetric studies of biomass characteristics show that hemicellulose decomposes in a temperature range of 250–500°C. Cellulose decomposes from 375–500°C, and lignin deteriorates evenly between hemicellulose and cellulose temperatures or occurs in a temperature range of 180–500°C [41]. Lignin has a rigid and complex nature and functions as an adhesive between cell walls so that the time it takes to degrade is longer than in the case of hemicellulose and others [42]. Hemicellulose indicates the highest or most drastic weight loss, while lignin has the lowest weight loss [43]. This is because hemicellulose is the most thermally unstable component. Therefore, hemicellulose breaks down faster and occurs at lower temperatures when compared to cellulose and lignin [44].

Writing paper contains compound components consisting of cellulose, hemicellulose, $CaSO_4$, $CaCO_3$, additives, binders, resins, and
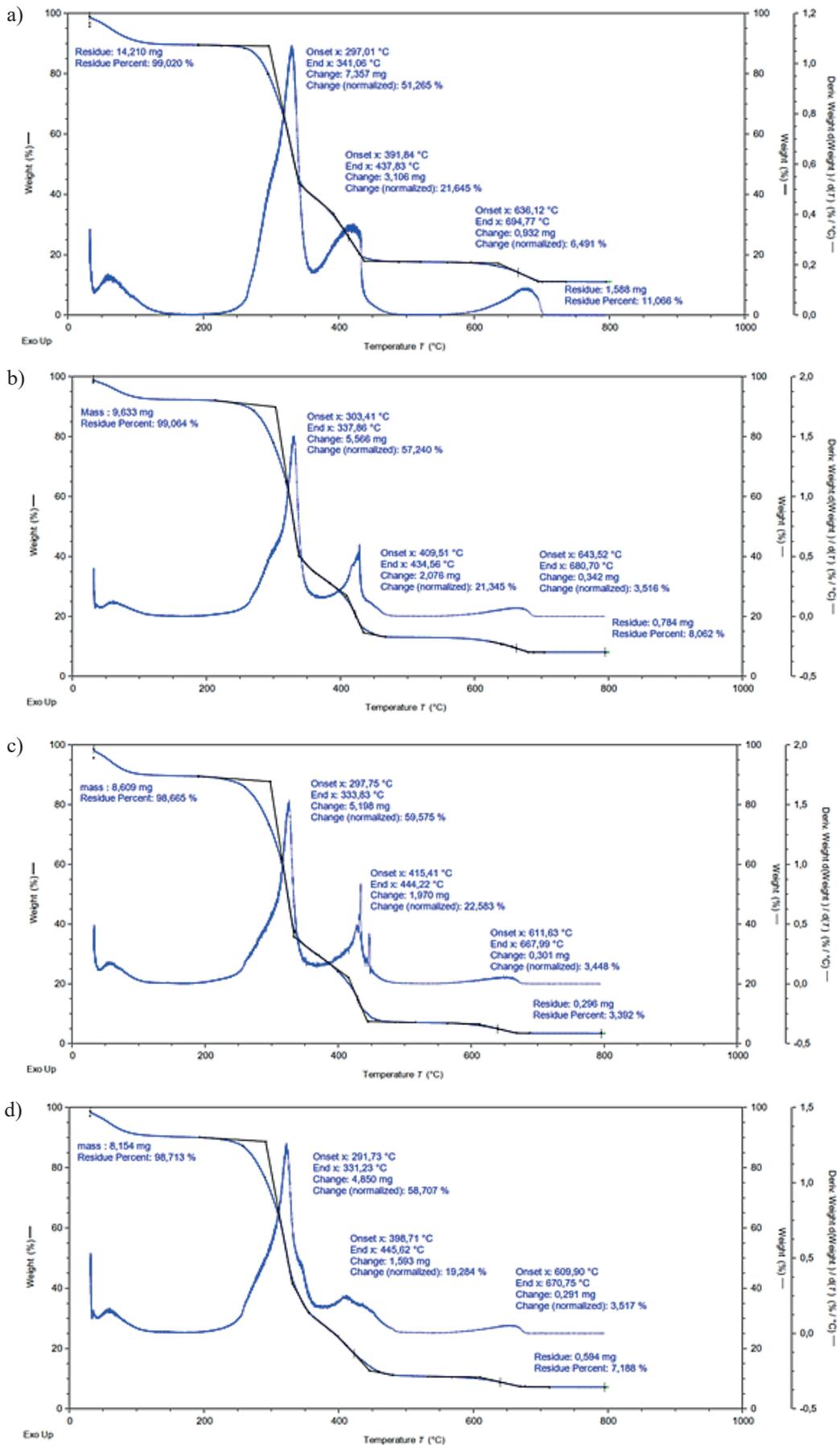
Figure 4. Thermogravimetry analysis / derivative thermogravimetry each variation of the pellets used: a) K100, b) K75, c) K50, d) K25, e) K0
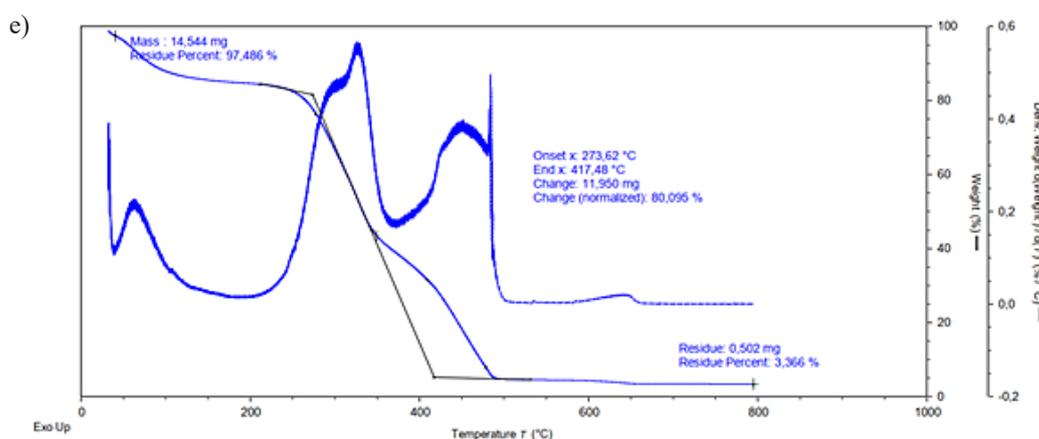
e)

Figure 4. Cont. Thermogravimetry analysis / derivative thermogravimetry each variation of the pellets used: a) K100, b) K75, c) K50, d) K25, e) K0

several other materials. The main components of paper are hemicellulose and cellulose as organic constituents. The overall reaction that will occur when heating consists in the degradation of cellulose, hemicellulose, and other additives from paper. The response in the temperature range 250–370°C is the degradation of hemicellulose, resulting from the reaction, which is a gas and volatile intermediates. Then, the response in the temperature range of 300–400°C is the degradation of cellulose, where cellulose has higher thermal stability than hemicellulose [45].

CONCLUSIONS

The addition of paper waste contributes to decreasing the water content. Simultaneously, garden waste accumulation involves decreasing the ash content and increasing heating value, increasing the carbon and hydrogen content, and reducing the oxygen and nitrogen levels. In the TGA/DTG analysis, garden waste makes the achievement of thermal stability temperature faster, which is due to the presence of organic compounds. On the basis of the TGA/DTG analysis, the pelletization process affects combustion stability and increased oxidation activation so that it is easier to ignite, and the combustion process becomes faster.

Acknowledgments

REFERENCES

1. Widyarsana I.M.W., Zafira A.D. 2015. Study On The Development Of Solid Waste Management In Tangerang. Jurnal Teknik Lingkungan, 21, 87.

2. Hasibuan H.S., Soemardi T.P., Koestoer R., Moersidik S. 2014. The Role of Transit Oriented Development in Constructing Urban Environment Sustainability, the Case of Jabodetabek, Indonesia. Procedia Environmental Sciences, 20, 622.

3. Debataraja I.B., Pradana D.H., Winarni N.L. The impact of landuse and the relationship between NDVI on the bird species richness in Sukmajaya District, Depok. IOP Conference Series: Earth and Environmental Science, 846(1). (2021)

4. Latianingsih N., Susyanti D.W., Mariam I. 2019. Model Kebijakan Pengelolaan Sampah Daerah Dalam Mewujudkan Masyarakat Sejahtera. Epigram, 16(1), 145.

5. Annisa B. 2019. Asesmen Aliran Kritis Sistem Pengelolaan Sampah Perkotaan di TPA Sampah. SPECTA Journal of Technology, 1(2), 41.

6. Ismiyati, Purnawan I., Kadarisman M. 2016. Effectiveness of environmental management based on trash in the city of Depok. MATEC Web of Conferences, 58.

7. Sagala G., Kristanto G.A., Kusuma M.A., Rizki S. 2018. Assessment of municipal solid waste as refuse derived fuel in the cement industry. International Journal on Advanced Science, Engineering and Information Technology, 8(4), 1062.

8. Sharon C., Sharon M. 2013. Studies on biodegradation of polyethylene terephthalate: A synthetic polymer. Journal of Microbiology and Biotechnology Research, 2(2), 248. Retrieved from https://jmbronline.com/index.php/JMBR/article/view/106

9. Sarwono A., Septiariva I.Y., Qonitan F.D., Zahra N.L., Sari N.K., Fauziah E.N., Suryawan I. W.K.

2021. Municipal Solid Waste Treatment for Energy Recovery Through Thermal Waste-To-Energy in Depok City, Indonesia. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 85.

10. Saputro H., Liana D.N., Firdaus A., Mahmudin M., Evan B., Karsa B.S., Fitriana L. 2018. Preliminary study of pellets Refuse Derived Fuel (RDF-5) based on Durian waste for feedstock in fast pyrolysis. IOP Conference Series: Materials Science and Engineering, 434(1).

11. Novita D.M., Damanhuri E. 2009. Perhitungan Nilai Kalor Berdasarkan Komposisi dan Karakteristik Sampah Perkotaan di Indonesia dalam Konsep Waste To Energy. Jurnal Teknik Lingkungan, 16(2), 103.

12. Rezaei H., Yazdan Panah F., Lim C.J. 2020. Sokhansanj S. Pelletization of Refuse-Derived Fuel with Varying Compositions of Plastic, Paper, Organic and Wood. Sustainability.

13. Białowiec A., Pulka J., Stępień P., Manczarski P., Gołaszewski J. 2017. The RDF/SRF torrefaction: An effect of temperature on characterization of the product – Carbonized Refuse Derived Fuel. Waste Management, 70, 91.

14. Zhou H., Meng A., Long Y., Li Q., Zhang Y. 2014. An overview of characteristics of municipal solid waste fuel in China: Physical, chemical composition and heating value. Renewable and Sustainable Energy Reviews, 36, 107.

15. Ariefin, Sariyusda, Jannifar, Mawardi I., Franky. 2018. Efektifitas Modifikasi Lubang Cetakan terhadap Karakteristik Wood Pellet. Proceeding Seminar Nasional Politeknik Negeri Lhokseumawe, 2(1), 66.

16. Zulfian F.D., Setyawati D., Nurhaida R.E. 2015. Kualitas biopelet dari limbah batang kelapa sawit pada berbagai ukuran serbuk dan jenis perekat. Jurnal hutan lestari, 3(2), 208.

17. Damayanti R., Lusiana N., Prasetyo J. 2017. Studi Pengaruh Ukuran Partikel dan Penambahan Perekat Tapioka terhadap Karakteristik Biopelet dari Kulit Coklat (Theobroma Cacao L.) Sebagai Bahan Bakar Alternatif Terbarukan. Jurnal Teknotan, 11(1).

18. Widjaya E.R., Triwahyudi S., Hadiwibowo S., Boulevard J.S. 2019. Performance Test of Biomass Pellet Plant Machinery using Rice Husk as Raw Material. Jurnal Enjiniring Pertanian, 11(2), 39.

19. Junaidi, Ariefin, Mawardi I. 2017. Pengaruh Persentase Perekat Terhadap Karakteristik Pellet Kayu Dari Kayu Sisa Gergajian. Jurnal Mesin Sains Terapan, 1(1), 13.

20. Hendrawan I., Haifan M., Mesin T., Teknik P., Otomotif M. 2020. Pengelolaan sampah menjadi energi berbasis tempat olah sampah setempat (toss) di kota tangerang selatan. Abdi Laksana: Jurnal Pengabdian Kepada Masyarakat, 1, 1.

21. Abdollahi M.R., Ravindran V., Svihus B. 2013. Pelleting of broiler diets: An overview with emphasis on pellet quality and nutritional value. Animal Feed Science and Technology, 179(1–4), 1.

22. Gendebien A. 2003. Refuse derived fuel, current practice and perspectives. WRc Ref: CO5087-4.

23. Paskawati Y.A., Susyana, Antaresti, Retnoningtyas E.S. 2011. Pemanfaatan sabut kelapa sebagai bahan baku pembuatan kertas komposit alternatif. Jurnal Widya Teknik, 9, 12.

24. Tchobanoglous G., Vigil S.A. 1993. Integrated solid waste managementengineering principles and management. New York: McGraw-Hill.

25. Basri E., Wahyudi I. 2013. Sifat Dasar Kayu Jati Plus Perhutani Dari Berbagai Umur Dan Kaitannya Dengan Sifat Dan Kualitas Pengeringan. Jurnal Penelitian Hasil Hutan, 31(2), 93.

26. Suryawan I.W.K., Fauziah E.N., Septiariva I.Y., Ramadan S., Sari M.M., Ummatin K.K., Lim J. 2022. Pelletizing of Various Municipal Solid Waste : Effect of Hardness and Density into Caloric Value. Ecological Engineering & Environmental Technology (EEET), 23(2), 122.

27. Sukarta I.N., Ayuni S. 2016. Analisis Proksimat dan Nilai Kalor pada Pelet Limbah Bambu. Sains dan Teknologi, 5(1), 752.

28. Gifani M., Qadry A., Saputro D.D., Widodo R.D. 2019. Karekteristik Dan Uji Pembakaran Biopelet Campuran Cangkang Kelapa Sawit Dan Serbuk Kayu Sebagai Bahan Bakar Alternatif Terbarukan. Karekteristik Dan Uji Pembakaran Biopelet Campuran Cangkang Kelapa Sawit Dan Serbuk Kayu Sebagai Bahan Bakar Alternatif Terbarukan, 16(2), 177.

29. Hasna A.H., Sutapa J.P.G., Irawati D. 2019. Pengaruh Ukuran Serbuk dan Penambahan Tempurung Kelapa Terhadap Kualitas Pelet Kayu Sengon. Jurnal Ilmu Kehutanan, 13(2), 170.

30. Ristianingsih Y., Ulfa A., Syafitri K.S.R. 2015. Pengaruh Suhu Dan Konsentrasi Perekat Terhadap Karakteristik Briket Bioarang Berbahan Baku Tandan Kosong Kelapa Sawit Dengan Proses Pirolisis. Konversi, 4(2), 16.

31. Mustamu S., Hermawan D., Pari G. 2018. Karakteristik biopelet Dari limbah padat kayu putih dan gondorukem. Jurnal Penelitian Hasil Hutan, 36(3), 191.

32. Pasek A.D., Gultom K.W., Suwono A. 2013. Feasibility of recovering energy from municipal solid waste to generate electricity. Journal of Engineering and Technological Sciences, 45(3), 241.

33. Putri A.P., Sukandar S. 2013. Studi Pemanfaatan Limbah B3 Sludge Produced Water Sebagai Bahan Baku Refuse Derived Fuel (RDF). Jurnal Teknik Lingkungan, 19(1 SE), 1.

34. Santosa S., Soemarno S. 2016. Peningkatan Nilai Kalor Produk Pada Produk Proses Bio-drying

Sampah Organik. Indonesian Green Technology Journal, 3(1), 29.

35. Amirta R., Anwar T., Sudrajat Yuliansyah, Suwinarti W. 2018. Trial production of fuel pellet from Acacia mangium bark waste biomass. IOP Conference Series: Earth and Environmental Science, 144(1).

36. Purwanto W.W., Supramono D., Fisafarani H. 2010. Biomass Waste and Biomass Pellets Characteristics and Their Potential in Indonesia. Chemical Engineering, (November), 1.

37. Mardiah A. 2019. Pembuatan dan Pengujian Karakteristik Briket dari Sampah Daun dan Kertas di PT. Indonesia Power UP Suralaya Banten. Bogor: IPB University.

38. Wiyoto Y.W.P., Budiana E.P., Himawanto D.A. 2018. Analisa thermogravimetry pada pirolisis limbah pertanian. Jurnal Teknik Mesin Indonesia, 11(1), 25.

39. Mayasari H.E., Yuniari A. 2016. Effect of vulcanization system and carbon black on mechanical and swelling properties of EPDM blends. Majalah Kulit, Karet, dan Plastik, 32(1), 59.

40. Boumanchar I., Chhiti Y., M'hamdi Alaoui F.E., El Ouinani A., Sahibed-Dine A., Bentiss F., Bensitel M. 2017. Effect of materials mixture on the higher heating value: Case of biomass, biochar and municipal solid waste. Waste Management, 61, 78.

41. Brand M.A., de Barnasky R.R.S., Carvalho C.A., Buss R., Waltrick D.B., Jacinto R.C. 2018. Thermogravimetric analysis for characterization of the pellets produced with different forest and agricultural residues. Ciencia Rural, 48(11).

42. Lukmandaru G., Susanti D., Widyorini R. 2018. Chemical properties of modified mahogany wood by heat treatment. Jurnal Penelitian Kehutanan Wallacea, 7(1), 37.

43. Alfredsen G., Bader T.K., Dibdiakova J., Filbakk T., Bollmus S., Hofstetter K. 2012. Thermogravimetric analysis for wood decay characterisation. European Journal of Wood and Wood Products, 70(4), 527.

44. Burhenne L., Messmer J., Aicher T., Laborie M.P. 2013. The effect of the biomass components lignin, cellulose and hemicellulose on TGA and fixed bed pyrolysis. Journal of Analytical and Applied Pyrolysis, 101, 177.

45. Kumar R., Sharma V., Verma N., Diwan P.K., Kumar V., Kumar V. 2019. Analysis of writing/printing paper via Thermogravimetric Analysis: application in forensic science. Australian Journal of Forensic Sciences, 51(1), 22.