

REPROCESSING PLASTIC WASTE INTO PETROLEUM FRACTION BASED ON ZERO WASTE PRINCIPLE

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Abstract. Plastic waste is a global problem in every country, especially in Indonesia, where recycling industries are very few. Furthermore, aside from the expensive costs required, processed varieties are also highly limited. This study examines a simple method with good potentials to be developed by the government as well as the community and **the result of this study is expected to be one of the solutions in overcoming the waste problem.** Besides, based on data obtained from the Kebon Kongok Regional Landfill, West Lombok, the average composition of the community waste was almost 73.5% plastic, 24.6% organic materials and 1.9% B3 (dangerous and toxic material) waste. The method developed was very simple, as it involved heating a cleaned plastic mixture about 168°C in a closed system, and subsequently, the gas and smoke produced were liquefied and cooled. **Heating is carried out in a reactor made of stainless still with a total volume of about 20 liters equipped with temperature control.** Meanwhile, the remaining combustion that was in the molten phase was therefore molded into building materials, e.g., paving blocks, with compressive strength that is comparable to ordinary concrete. In addition, the results of liquid smoke condensation, further, produced two light fractions that were not mixed. GCMS analysis showed that the hydrocarbon compound has the number of carbons in range 8-12 atom for both fractions. Based on the FT-IR and UV-Vis spectrums confirmed the presence of aromatic benzene groups in both the fraction, while the second fraction contains more complex hydrocarbon than the first fraction. Major hydrocarbon in the first fraction is n-nonene and 5-methyl-1-heptene, whereas major hydrocarbon in the second fraction is n-nonene, 5-methyl-1-heptene and n-decene.

Keywords: Plastic waste, recycle, zero waste.

INTRODUCTION

Waste, especially the plastic variety, is a problem faced by all countries, both developed and developing, due to the difficulty of natural decomposition. Indonesia ranks second after China as a contributor to water bodies, especially the sea, reaching about 0.48 – 1.29 MMT/yr., with a WGR (waste generation rate) value of 0.52 kg/ppd (percent per day), and 83% of which is grossly mismanaged [1]. In addition, data estimating this condition in Indonesia are expected to exist within the next several decades if handling systems are continuously abused. Furthermore, difficulty in management and processing are constrained by various factors, including deficiency in governmental support in waste management as stipulated in the implementing legislation is still limited to collection, transportation, and disposal [2]. Therefore, community understanding and awareness of this problem are tremendously insufficient, especially in Lombok Island, which the deadest is in the Kebon Kongok Regional Landfill (final disposal site), with the abundant waste mounting up to approximately 100 meters. Based on the data presented by the Secretary of the Department of Environment and Forestry, West Nusa Tenggara, the total waste in 10 districts/cities of West Nusa Tenggara reaches 76.21 tons per day, and about 641.92 tons enter the landfill, and only 17% is recyclable [3]

In response to this challenge, many innovations have been conducted by, researchers, social activists and the government, including West Nusa Tenggara regional authority that single-handedly budgeted about IDR 15 billion to maximize its management process [4]. Furthermore, the improvements carried out by social activists were through the promotion of Waste Bank System, which was also welcomed well by the community, and interesting feedback from the collection was reported, including its conversion into compost, bags [5] from plastic, and various handicrafts from used goods. Meanwhile, researchers have applied themselves in processing plastic waste into interesting results, including PP, PET, and PE into Oil Fuel [6] and various types of non-recyclable forms of plastics have also been converted to gas and oil fuels with carbon ranging from C8 to C20, using the pyrolysis method [7]. Furthermore, processing HDPE into petroleum has also been conducted with the use of catalysts, to the point where crude oil (58 – 70%) was obtained [8]. In general, three methods most widely used in producing fuel from plastics include thermochemical treatment, hydrocracking, and catalytic conversion [9], meanwhile, these methods utilize organic solvents that subsequently cause new challenges, in the form of more waste. Furthermore, hydrocracking also involves hydrogen gas at high pressure.

The processing of plastic into handicraft products often ends up producing more waste because either the quality of the materials or the strength is considered to be lower than the supposed raw materials. Meanwhile, although the innovations conducted by previous researchers showed good results, it remains significantly difficult to apply in the proposals within the community. In addition, aside from being constrained by a complicated process that requires expertise, the nature of plastics to be processed stays limited. Furthermore, it is also important to recognize that the community generally has not been familiar with related codes used in daily life. Conversely, the problem of difficulty in processing within Indonesia has been identified to be as a result of the existing waste being already mixed without any form of sorting, enhancing the difficulty in treatment.

Therefore, this study examines a simple method with the potential to be developed, in order to be applied at the village level which is **simple technology, easy to operate for ordinary people and affordable costs**. In addition, plastic waste was processed into petroleum, producing (1) residue, which was specifically converted into products, with more permanent use, including paving blocks and asphalt, in an attempt to not create new waste potentials, and (2) oil fuel, obtained from the condensation of its heating smoke, which required the increase of some parameters, in other to involve its direct use in vehicles.

EXPERIMENT

Materials

The plastic waste used was collected from the community waste landfill in Mataram City, West Nusa Tenggara, and several chemicals were also used, including Acetone, deionized Aqua, and n-hexane. Furthermore, there was also some supporting equipment, encompassing scissors, paving block molds, hand press, and heating mantle, while the heating reactor was made through the use of a stainless drum, with a volume of up to 20 liters.

Methods

Plastic separated from organic waste was used, which was further cleaned from the residual soil or other organic components, glass or metal. All plastics of various types and sizes that are collected are then crushed into small pieces measuring about 1 cm² and placed in a heating reactor. Besides, the temperature and pressure were monitored in order to prevent an explosion, and the smoke from the process was channeled to a condenser, where the condensate was collected into a closed glass tube. Furthermore, the residue observed had melted perfectly, and therefore molded by using the paving block molds in hot conditions. These were, subsequently tested for physical properties, including mechanical strength and melting point, while the chemical composition of the oil condensed from the heating smoke was characterized using the UV-Vis spectrophotometer, Fourier-Transform Infra-Red (FT-IR), and GC-MS (Gas Chromatography and Mass Spectroscopy).

RESULT AND DISCUSSION

Waste obtained at each collection point is then identified as organic waste, plastic waste and hazardous toxic materials which are then weighed respectively. the proportion of each type of waste is then converted into percent of total weight. The average composition of the waste obtained included organic components (48.87 – 55.45% (wt.)), most of which originated from unsold vegetable, leftover food, and dry leaves, while the amount of plastic contributed 39.01 – 42.81% (wt.) which mean that for every 100 kg of garbage, there are 39.01-42.80 kg of plastic waste, and others, including glass, metal, etc., comprised 1.05 – 1.74% (wt.). In addition, the average plastic-type composition identified is presented in Fig. 1, where it is seen to be dominated by LDPE type, which originates from food packaging's encompassing snack, plastic wrap, and bag. Furthermore, numerous HDPE types from soap packs, shampoo containers, milk bottle, etc., were also noted, while the PP type were mostly residues of the broken household furniture, comprising chairs, clothes hanger, food containers, etc.

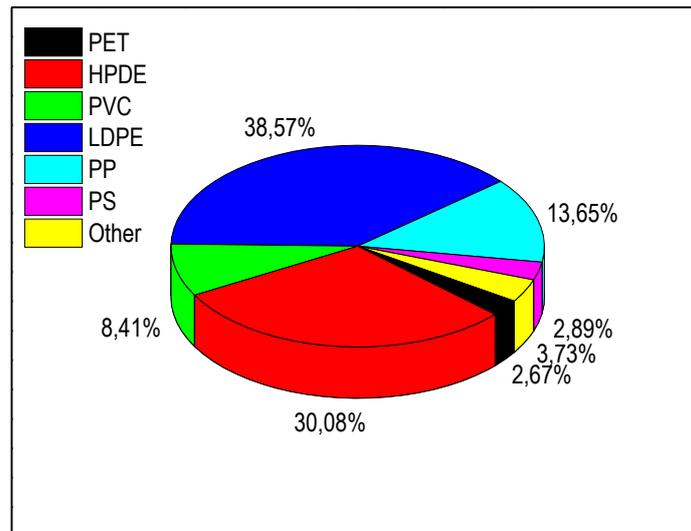


Fig. 1. The average composition of plastic types identified from the landfill in the environment of Mataram city, West Nusa Tenggara.

From the results of the heating procedure, the product in the form of residue (75.86% (wt)) was obtained, which was subsequently processed into paving blocks, and oil condensates (21.03% (wt)), specifically filtered, to produce two liquid fractions that were not mixed as shown in Fig. 2. In addition, the lost mass from this result was because condensation did not occur with all the gases that were produced, and this result was similar to previous studies that used plastic types composition of HDPE (26.2 wt%), LDPE (31.1 wt%), PP (8.2 wt%), and PS (13.0 wt%), which produced oil products amounting to 29.00% [7]. However, this was also extremely far from the research carried out by William *et al.*, using the same method, although with the Parr mini benchtop reactor, at a temperature of 500°C, where pyrolysis was conducted on the sorted PE, PP, PS, and PET plastics, and the crude oil produced were 93% (wt), 95% (wt), 71% (wt), and 15% (wt), respectively [10] while those mixed with a Proprietary reactor (Natural State Research Inc.), at temperatures of 370 – 420°C, produced crude oil that reached 90% [11]. The result obtained in this investigation was way lower than the observations from previous studies because the technology used was a reactor, which was more compact, integrated, and advanced. This also caused difficulty in applying the technology within the community, especially in Indonesia. Meanwhile, the presence of PVC and other types of plastic in this report also slowed down the degradation process, because they cannot be degraded in one stage when compared with others [12].

Based on the mechanical properties conducted on the paving blocks fabricated, the average value of compressive strength obtained was 139.42 kg/cm², which was close to, although not exceeding the concrete sample (142.30 kg/cm²) because the residue was not homogeneous. This was as a result of the distribution of aluminum foil originating from LDPE, usually used for food or snack packaging. In addition, its melting point was at a temperature of about 187°C, because the composition of the waste used was dominated by LDPE (135°C) and HDPE (145°C). Meanwhile, co-pyrolysis on HDPE, LDPE, and PP plastics conducted in previous studies were at a temperature of 400 – 600 °C, with optimum conditions at a temperature of 500 – 525 °C [13] and the color of the resulting paving blocks were jet black. This was because during the process, direct combustion of e.g., Tar and the remnant hydrocarbon, occurred spontaneously and occasionally, as a result of the gases produced being highly flammable. Hence, this part of the residue contained hydrocarbon compounds with an atomic number of C ranging from 8 – 24 [14].



Fig.2. Paving blocks (left) from the residue of plastic waste heating and two oil fractions from heating smoke of plastic waste (right).

The condensed smoke formed 3 main phases that were not homogeneous, hence, filtration was conducted, and 2 phases of liquid were subsequently formed, with a bright yellow colored variety above and a brownish-yellow below (Fig. 2). In addition, the 1st fraction had a density of 0.704 g/mL, while the second was 0.789 g/mL, and qualitative tests were further carried out, including UV-Vis absorption. This was actually very important in the confirmation of the presence of compounds with double or conjugated double bonds, considering that some plastics contain monomers with these characteristics. Furthermore, the results obtained for the 2nd fraction (brownish yellow) showed absorption peaks at 266 nm and 361 nm, as shown in Fig. 3, while the 1st fraction (bright yellow) displayed at 255 nm, indicating that the 2nd contained compounds with more conjugated double bonds. Tab. 1 and 2 further demonstrated the presence of a larger aromatic composition, with a width of the area reaching 15.85% (ethyl-benzene; 1, 5-dimethyl-benzene; 1, 3, 5-trimethyl-benzene) in the first fraction, while the second had only about 0.45% (ethyl-benzene). This was not surprising because the type of plastic used also contained PS (polystyrene) and the condensation of smaller molecules at a fairly high temperature and pressure also promotes the formation of molecules with conjugated double bonds.

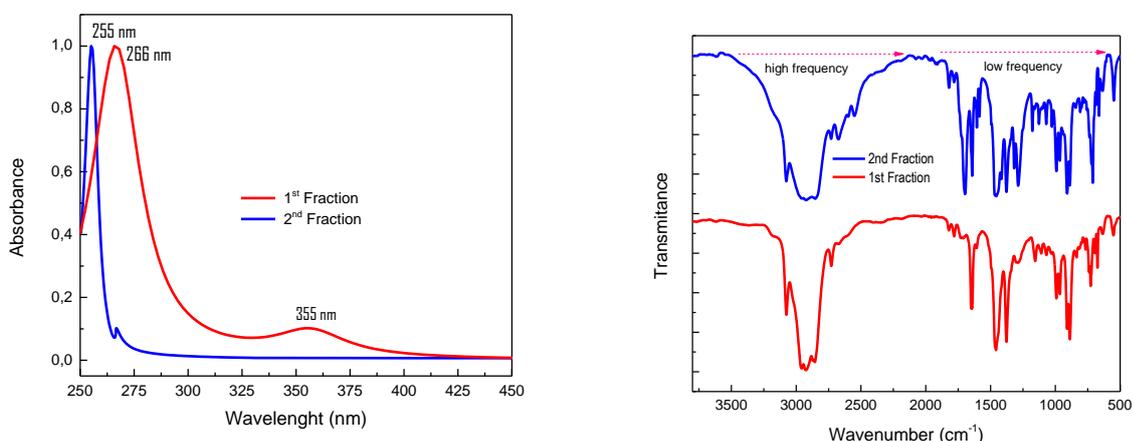


Fig.3. UV-Vis Absorbance (left) and FT-IR Transmittance spectra of plastic waste fraction oil.

Besides the UV-Vis absorption test, FT-IR Spectrum transmittance infrared evaluation was also conducted, based on its ability to confirm the functional groups of the existing compounds, in order to enhance appropriate classification. In addition, the data showed strong absorption within the area of 2700 – 3200 cm⁻¹ (high frequency), indicating the stretching of C-H bonds from hydrocarbons (Fig. 3), and the 2nd fraction comparatively showed broader absorptions at high-frequency regions. This was presumably because it contained an alcohol compound as shown in Tab.2, with an O-H group that conferred a stretching vibration mode with strong and broad absorption in the area of 3100 – 3400 cm⁻¹. Moreover, for 500 – 1700 cm⁻¹ (low frequency), the 2nd fraction tends to show a more complex absorption mode. Tab. 1 and 2 with regards

to GCMS results showed the 2nd fraction to contain compounds with more complex structures. However, both contained a compound with oxygen atoms in the form of carbonyl (alkanal (aldehyde), alkanon (ketone), and ester groups) [9], confirmed through the absorption at a wavenumber of 1680 – 1715 cm⁻¹ in both spectra.

Table 2. GCMS results for the first fraction oil of plastic waste

Peak No.	Compound	% Yield	Group	Formula
1	1-Decena	0.54	Alkene	C ₁₀ H ₂₀
2	1,4-Hexadiena	0.62	Alkene	C ₈ H ₁₄
3	1,4-dimethyl-Cyclohexane,	0.42	Alkane	C ₈ H ₁₆
4	2,5-dimethyl 1-Hexena,	0.49	Alkene	C ₈ H ₁₆
5	1-Oktena	6.18	Alkene	C ₈ H ₁₆
6	Cyclohexena	0.78	Alkene	C ₈ H ₁₄
7	Octane	4.62	Alkane	C ₈ H ₁₈
8	1,1,3,4-tetramethyl-Cyclopentane	1.35	Alkane	C ₉ H ₁₈
9	3,3,5-trimethyl-1-Hexene	0.57	Alkene	C ₉ H ₁₈
10	2,4-dimethyl-Heptane	1.10	Alkane	C ₉ H ₂₀
11	1,3,5-trimethyl-Cyclohexane	3.13	Alkane	C ₉ H ₁₈
12	4,4,5-trimethyl-2-Hexene	4.84	Alkane	C ₉ H ₁₈
13	5-methyl-1-Heptene	8.79	Alkene	C ₈ H ₁₆
14	2-ethyl-Bicyclo[2.2.1]heptane	1.09	Alkane	C ₉ H ₁₆
15	1,3,5-trimethyl-Cyclohexane	5.35	Alkane	C ₉ H ₁₈
16	ethyl-Benzene	1.50	Arene	C ₈ H ₁₀
17	Diisoamylene	0.96	Alkene	C ₁₀ H ₂₀
18	1,2-dimethyl-Benzene	6.09	Arene	C ₈ H ₁₀
19	1-Dodecyne	0.84	Alkane	C ₁₂ H ₂₂
20	2-propenyl-Cyclohexane	0.59	Alkane	C ₉ H ₁₆
21	6,6-Dimethyl-Hepta-2,4-Diene	1.91	Alkene	C ₉ H ₁₆
22	1,1'-(1,2-ethanediyl)bis-Cyclopropane	1.48	Alkane	C ₈ H ₁₄
23	3,3,6-trimethyl-1,5-Heptadien-4-on	1.32	Alkanon	C ₁₀ H ₁₆ O
24	1,1,2,3,3-pentamethyl-Cyclobutane	1.12	Alkane	C ₉ H ₁₈
25	1-Nonene	12.95	Alkene	C ₉ H ₁₈
26	4-Nonene	2.56	Alkene	C ₉ H ₁₈
27	2,6-Dimethyl Hept-5-En-1-Al	2.15	Aldehyde	C ₉ H ₁₆ O
28	1,4-dimethyl-5-(1-methylethyl)-Cyclopentene	0.92	Alkene	C ₁₀ H ₁₈
29	Cyclopropyliden	2.83	Alkene	C ₉ H ₁₈
30	pentyl-Cyclopentane	0.78	Alkane	C ₁₀ H ₂₀
31	7-methyl-4-undecene	0.84	Alkane	C ₁₂ H ₂₄
32	4-Decene	0.63	Alkene	C ₁₀ H ₂₀
33	7-methyl-3-Octyne	1.94	Alkuna	C ₉ H ₁₆
34	propyl-Benzene	1.30	Arene	C ₉ H ₁₂
35	3,7-dimethyl-1-Octene	0.82	Alkene	C ₁₀ H ₂₀
36	1,3,5-trimethyl- Benzene	3.07	Arene	C ₉ H ₁₂
37	1,3,5-trimethyl- Benzene	3.08	Arene	C ₉ H ₁₂
38	1,11-Dodecadiene	1.29	Alkene	C ₁₂ H ₂₂
39	1,9-Decadiene	4.69	Alkene	C ₁₀ H ₁₈
40	1-Decene	4.49	Alkene	C ₁₀ H ₂₀

The results of GCMS screening showed the composition of hydrocarbon compounds that are almost similar to both, comprising of a compound with the number of carbon atom ranging from 8 – 12. This was narrower when compared with previous reports that involved thermal treatment with atmospheric oxygen at a temperature of 370 – 420°C, which produced hydrocarbon fraction between C₄H₈ and C₂₈H₅₈ [11]. Furthermore, the overall structure was dominated by Alkane groups, including the forms of aliphatic and cyclic, as well as compounds containing oxygen atoms. In addition, the 1st fraction showed compounds with oxygen content reaching 3.47% (wt), and the 2nd was 4.43% (wt), which were quite high, with low-calorie value, which is capable of causing poor corrosion and stability [15]. This was not surprising because, besides the plastic used, the process involved conditions with free air. However, the thermal treatment that involved non-catalytic pyrolysis was capable of producing fractions with lower oxygen content, when compared with other methods [16]. Furthermore, the results of separation and identification by GCMS showed an almost similar composition in both fractions, where numerous compounds were identified, including 1-decene, 1-nonene, ethyl-benzene, and others. Meanwhile, the

2nd fraction specifically contained (1S, 2S, 3S, 5R) (-)-Isopinocampheol and 2-propenoic acid, and 5-methylene-6-heptenyl ester.

Table 2. GCMS results for the second fraction oil of plastic waste

Peak No.	Compound	% Yield	Group	Formula
1	trans-2-Decenal	0.22	Alkanal	C ₁₀ H ₁₈ O
2	2-Methyl-1-heptene	0.27	Alkene	C ₈ H ₁₆
3	n-1-Octene	5.58	Alkene	C ₈ H ₁₆
4	Octane	4.90	Alkane	C ₈ H ₁₈
5	1,1,3,cis-4-tetramethylcyclopentane	0.68	Alkane	C ₉ H ₁₈
6	1,3,5-Trimethylcyclohexane	1.19	Alkane	C ₉ H ₁₈
7	Ethyl-cyclohexane	0.69	Alkane	C ₈ H ₁₆
8	4,4,5-trimethyl-2-Hexene	1.26	Alkene	C ₉ H ₁₈
9	5-Methyl-1-heptene	16.46	Alkene	C ₈ H ₁₆
10	4-Ethyl-Cyclohexene	0.23	Alkane	C ₈ H ₁₄
11	1,3,5-Trimethylcyclohexane	2.29	Alkane	C ₉ H ₁₈
12	Ethyl-benzene	0.48	Arene	C ₈ H ₁₀
13	6-Methyl-1-Octene	0.78	Alkene	C ₉ H ₁₈
14	NA	2.21	NA	NA
15	3-Methyloctane	0.41	Alkane	C ₉ H ₂₀
16	1-ethenyl-2-methyl-, trans-Cyclohexane	0.72	Alkane	C ₉ H ₁₆
17	1-Propyl-3-cyclohexane	0.56	Alkane	C ₉ H ₁₆
18	6,6-Dimethyl-2,4-heptadiene	0.86	Alkene	C ₉ H ₁₆
19	1,2-dicyclopropyl-ethane	2.12	Alkane	C ₈ H ₁₄
20	1,cis-2,trans-4-Trimethylcyclopentane	1.27	Alkane	C ₈ H ₁₆
21	n-Nonene	15.28	Alkene	C ₉ H ₁₈
22	Isocitronellen	1.07	Alkene	C ₁₀ H ₁₈
23	Nonane	5.70	Alkane	C ₉ H ₂₀
24	2,6-Dimethyl-hept-5-1-al	2.80	Alkanal	C ₉ H ₁₆ O
25	2-Ethylbicyclo[2.2.1]heptane	0.85	Alkane	C ₉ H ₁₆
26	2-propenoic acid, 5-methylene-6-heptenyl ester	0.57	Ester	C ₁₁ H ₁₆ O ₂
27	NA	1.01	NA	NA
28	Propyl-cyclohexane	1.29	Alkane	C ₉ H ₁₈
29	n-Butyl-cyclopentane	0.91	Alkane	C ₉ H ₁₈
30	(1S,2S,3S,5R)-(+)-Isopinocampheol	0.84	Alcohol	C ₁₀ H ₁₈ O
31	2,6-Dimethyl-2-octene	0.47	Alkane	C ₁₀ H ₂₀
32	2-methylpropylidene-cyclopentane	2.10	Alkane	C ₉ H ₁₆
33	2,4-dimethyl-1-decene	2.03	Alkane	C ₁₂ H ₂₄
34	cis-Hexahydroindan	0.88	Alkane	C ₉ H ₁₆
35	NA	2.46	NA	NA
36	3-Ethyl-5-methyl heptane	2.18	Alkane	C ₁₀ H ₂₂
37	1,11-Dodecadiene	1.77	Alkene	C ₁₂ H ₂₂
38	1.9-decadiene	3.98	Alkene	C ₁₀ H ₁₈
39	3-methylene-Nonane	1.84	Alkane	C ₁₀ H ₂₀
40	1-Decene	8.79	Alkene	C ₁₀ H ₂₀

Moreover, the 1st fraction was dominated by 1-nonene (12.95%), 5-methyl-1-heptene (8.79%), and 1-octene (6.18%) (Tab. 1), while the 2nd contained a lot of 5-methyl-1-heptene (16.46%), n-nonene (15.28%), and 1-decene (8.79%). This led to the density of both fractions being highly similar and difficult to separate, and this did not concur with previous studies that based on non-recyclable plastic waste (HDPE, LDPE, PP, and PS), where the content in oil produced with carbon atoms ranged from 5 – 20 and was dominated by 2-ethyl-2-methyl-oxirane (18.85 %), 2-cyclopropyl-pentane (15.99%), and 2, 3-dimethyl-pentane (12.08%) [7]. Hence, the current research produced oils with lower density. Overall, the composition of liquid fuels obtained in this study both the first and second fractions are in accordance with the composition of commercial liquid fuels of PT. PERTAMINA Premium and Peralite type [17] and regular gasoline in general [18] that is mostly from cyclohexane, cycloheptane octane and so forth. but the proportion of each component of the compound needs to be further developed in order to obtain an appropriate octane number.

CONCLUSION

The results of this study show the propensity of applying the pyrolysis method with simple technology to process plastic waste into petroleum fractions. Furthermore, two products were obtained from the landfill in Mataram City, including

75.86% (wt) residue that was converted into paving blocks for permanent use, and 21.03% (wt) also oils with high-energy content, and potentials for development into alternative fuels. Therefore, the technology tends to be of great significance for further development, in an attempt to overcome the problems of waste, especially of the plastic form, which continues to increase daily.

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