Research Inventy: International Journal of Engineering And Science
Vol.14, Issue 5 (May 2024), PP 01-06
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

Characteristics of fuel resulting from the pyrolysis process of HDPE and PP plastic waste

I Made Mara[1*], I Made Nuarsa[2]

[1]*Department of Mechanical Engineering, Faculty of Engineering, University of Mataram. Jl. Majapahit No. 62 Mataram 83125 Indonesia Telp. (0370) 636087*

[2]*Department of Mechanical Engineering, Faculty of Engineering, University of Mataram. Jl. Majapahit No. 62 Mataram 83125 Indonesia Telp. (0370) 636087*

**Corresponding Author*

Abstract:*Plastic waste is one of the environmental pollution materials on a global scale, especially in Indonesia, because plastic waste is difficult to decompose in the soil. One way to overcome this is by recycling plastic waste. However, this method is not very effective, only about a few percent can be recycled, and the rest ends up in landfills. Another way to do this is to use plastic waste to process it into fuel using a pyrolysis process. This research was conducted to determine the effect of the type of plastic (HDPE and PP) and the amount of heat absorbed by the cooling water by varying the diameter of the heat exchanger (1/2 inch, 3/4 inch and 1 inch) on the physical properties of fuel oil using the pyrolysis process. From the test results, the maximum reactor temperature produced from each type of plastic waste decreases as the heat exchanger diameter increases. However, the volume and calorific value of the fuel produced increases. Generally, the physical properties of fuel oil produced from the pyrolysis process of plastic waste are close to the physical properties of gasoline..*

Keywords:*fuel, pyrolysis, plastic, waste, physical properties.*

Date of Submission: 24-04-2024 Date of acceptance: 02-05-2024

I. INTRODUCTION

The large amount of plastic waste is an indication of environmental pollution on a global scale, especially in Indonesia, because it is difficult for plastic waste to be decomposed in the soil. One way to overcome this is by recycling plastic waste (Mataram City Cleaning Department, 2012). However, this method is not very effective (Santoso, 2010), around a few percent can be recycled (Alit et al, 2024) and the rest piles up in rubbish dumps. Another way to do this is to use plastic waste to be processed into fuel oil using a pyrolysis process (Kadir, 2012).

One type of waste that is often encountered is plastic waste. The use of plastic tends to increase with the increasing number of industries and consumers who use it. Plastic waste needs to be handled seriously so as not to damage the environmental balance (Kurniawan and Nasrun, 2014). Based on data from the Mataram City Cleaning Service (2012), the amount of waste produced by Mataram City on average increases every year along with the rate of population growth. In a single day, waste production reaches 1,287 m^3/day, while the Mataram City Cleaning Service can transport 832 m^3 of waste/day. This condition means that only 64.6% of waste per day can be handled by the government, while the remaining 35.4% is handled with additional work policies. Apart from that, there were also those that were destroyed directly by the community.

Plastic has many advantages over other materials. In general, plastic has a low density (Wahyudi 2001), is electrically insulating, has varying mechanical strength, limited temperature resistance, and varying chemical resistance. Apart from that, plastic is also light, easy to design, and cheap to manufacture (Alfiando et al, 2019). One of the efforts made to create alternative energy is to convert plastic waste into fuel to replace fossil fuels (Ahmad, 2022). Plastic comes from petroleum derivatives so that in the decomposition process it can be returned to hydrocarbons as a basic energy material (Nuryosuwito et al, 2020). The plastic waste recycling process aims to convert long chain hydrocarbon polymers into shorter chains as raw materials for the chemical industry or fuel production.

Okariawan, et al (2011), have conducted research on the conversion of used oil into fuel oil using a thermal cracking process at varying heating temperatures and heat exchanger diameters. In the process of making fuel oil from used oil, the thermal cracking process is most effective at temperatures above 300 ^oC, namely from 1000 ml of used oil, an average of 90% is fuel oil and 10% is sediment. Apart from that, from testing the physical characteristics of fuel from used oil, it was found that the characteristics closest to diesel specifications were oil produced at a heat exchanger diameter of 3/4 inch at a heating temperature of 300 ^oC.

Plastic is a polymer that has unique and extraordinary properties. A polymer is a material consisting of molecular units called monomers (Novarini et al, 2021). If the monomers are the same it is called a homopolymer, and if the monomers are different it results in a copolymer. Plastic can be divided into two types, namely thermoset plastic and thermoplastic plastic. Thermoset plastic is a plastic that cannot be recycled because the polymer composition is in the form of a three-dimensional network (Jahiding et al, 2020). Examples are PU (Poly Urethene), UF (Urea Formaldehyde), MF (Melamine Formaldehyde), polyester, epoxy, and so on. Meanwhile, thermoplastic plastic is plastic that can be molded repeatedly in the presence of heat. Thermoplastic plastics include PP, PE, PS, ABS, SAN, nylon, PET, BPT, Polyacetal (POM), PC, cetal (POM), PC, and so on (Harper, 2000).

Polyethylene is a polymer material whose chemical properties are quite stable, resistant to various chemicals except halides and strong oxides. PE is generally white in color, translucent and has a density value ranging from 0.91 - 0.97 gr/cm3 (Erlangga et al, 2023). Polyethylene is made by polymerizing ethylene gas, which can be obtained by giving petrolium hydrogen gas to the breakdown of oil (naphtha), natural gas or acetylene. Polyethylene is divided based on its density, among others (Mujiarto, 2005); High density polyethylene (HDPE) is thermoplastic polyethylene made from petroleum. It requires 1.75 kg of petroleum (as energy and raw material) to make 1 kg of HDPE. Meanwhile, HDPE has a density of 0.95-0.97gr/cm^3, and is crystalline (90% crystallinity) (Erlangga et al, 2023). HDPE is widely used in products and packaging such as milk bottles, detergent bottles, margarine, waste containers, lubricant jerry cans and water pipes (Harper et al 2003). LDPE has a density of 0.92 gr/cm^3. The melting temperature for LDPE is 105oC (Erlangga et al, 2023).

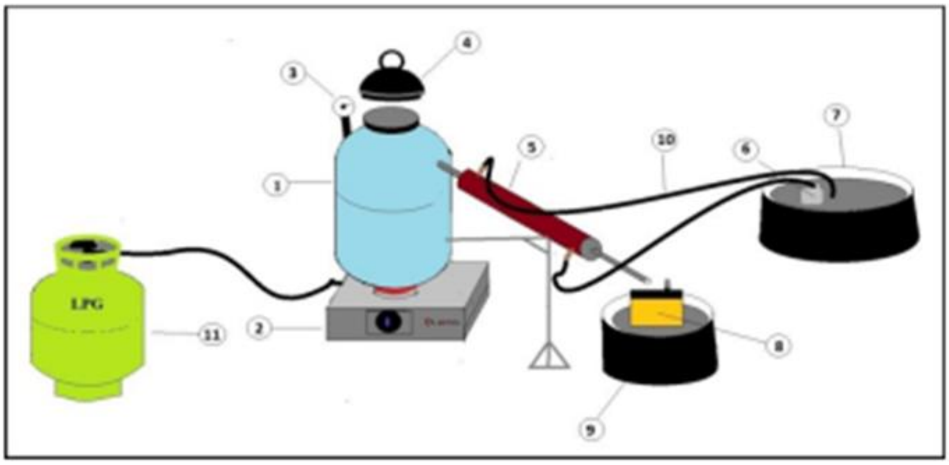
Polypropylene is similar to polyethylene, but has better physical strength due to its lower density (Adoe et al, 2016). Polypropylene is a light plastic with a density of 0.900-0.915 g/cm^3 (Erlangga et al, 2023). Polypropylene molecules contain tertiary carbon atoms with main chain methyl groups. The hydrogen atom is bonded to a tertiary carbon atom which easily reacts with oxygen and ozone, which causes its oxidation resistance to be lower than polyethylene (Panda, 2011).

Converting plastic waste into fuel oil includes tertiary recycling (Sari, 2017). Converting plastic waste into fuel oil can be done using a cracking process (Rodiansono et al, 2007, Okariawan et al, 2011). Cracking is the process of breaking down polymer chains into compounds with lower molecular weights. The results of this plastic cracking process can be used as chemicals or fuel. There are three types of cracking processes (Panda, 2011).

II. EXPERIMENTAL PROCEDURE

The materials used in this research were HDPE/P1 plastic waste (oil bottles) and PP/P2 plastic waste (drinking water bottles). Before processing, the plastic waste is cleaned first, then cut into pieces, dried, then weighed (1 kg of plastic waste for each process of making fuel oil). The method used in this research is an experimental method by making pyrolysis equipment, then testing the performance of the equipment by varying the diameter of the heat exchanger and the type of plastic waste used. Next, test the physical properties of the fuel oil produced so that it can be compared with standard diesel or gasoline fuel, as well as fuel oil from other plastic waste.

Figure 1. Pyrolysis apparatus; 1 Pyrolysis reactor 2. Heater 3. Thermometer 4. Cover 5. Heat exchanger 6. Pump, 7. Cooling media 8. Condensate reservoir 9. Condensate cooler reservoir 10. Hose 11. LPG fuel.



This research was carried out in two stages. First, the stage of making fuel oil from plastic waste using a tool designed with various types of plastic and various heat exchanger diameters. The plastic waste used in this research came from two different types of plastic, namely high density polyethylene (HDPE/P1) oil bottles and polyporpilyne (PP/P2) drinking water bottles. The variations in heat exchanger diameter used are D1 = 1/2 inch, D2 = 3/4 inch and D3 = 1 inch. And the second stage is research on the physical properties of the fuel oil produced. The process of making fuel oil is carried out three times for each type of plastic and variation in heat exchanger diameter. In the process of making fuel oil, each type of plastic is put into the reactor with a mass of 1kg. Because the density of P2 is smaller than P1, P2 fills the space in the reactor most fully.

Figure 2. Fuel resulting from the pyrolysis process

III. RESULTS AND DISCUSSIONS

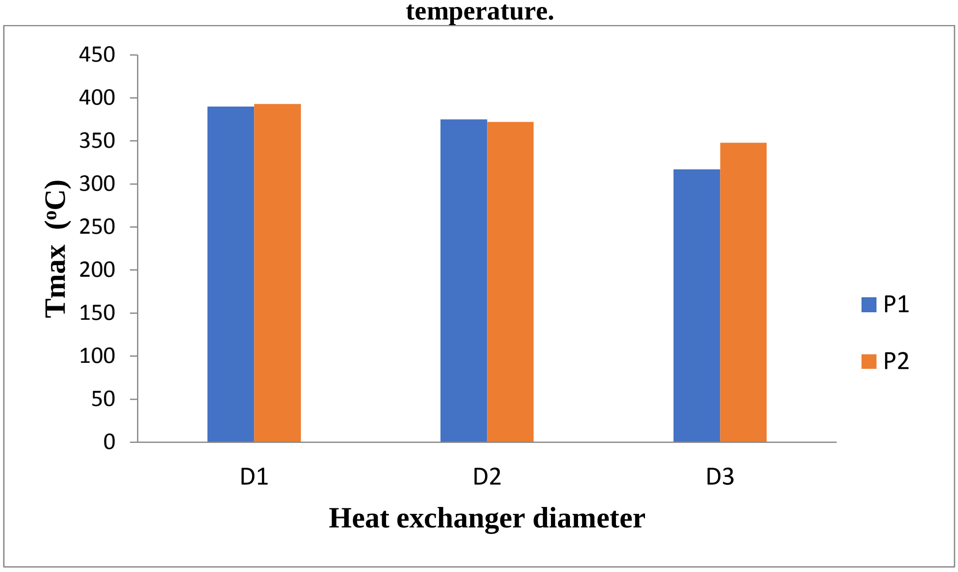
This fuel manufacturing process was carried out three times for each type of plastic and variation in heat exchanger diameter. In the process of making this fuel, each type of plastic is put into the reactor with a mass of 1kg. In the fuel manufacturing process, data on manufacturing results was obtained including the maximum temperature (Tmax of the reactor) in the plastic waste reactor tube as shown in table 1 below.

Table 1.Pyrolysis process temperature data

Sample	Tmax (°C)	Sample	Tmax (°C)
	385		390
P1D1	395	P2D1	400
	390		390
Average	**390**	**Average**	**393**
	370		370
P1D2	380	P2D2	365
	375		380
Average	**375**	**Average**	**372**
	315		350
P1D3	320	P2D3	350
	315		345
Average	**317**	**Average**	**348**

In table 1 above, it can be seen that the reactor temperature in the pyrolysis process for HDPE material with a heat exchanger diameter of ½ inch averages at 390°C, while for PP material it is slightly higher, namely 393 °C. At a heat exchanger diameter of ¾ inch the average temperature is 375 °C and 272 °C for HDPE and PP materials, respectively. Likewise, at a heat exchanger diameter of 1 inch, the maximum temperature in the pyrolysis reactor chamber is 317 °C and 348 °C for HDPE and PP materials, respectively. The maximum temperature in the pyrolysis reactor tube will decrease if the diameter of the heat exchanger is increased, this happens because the rate of pyrolysis gas leaving the reactor increases and undergoes a cooling process which then turns into liquid fuel.

Figure 3. Relationship between plastic waste type and heat exchanger diameter on maximum temperature.



From figure 3. it can be seen that the average maximum temperature for HDPE plastic (P1) for each heat exchanger diameter variation is 390°C, 375°C and 317°C, respectively. Meanwhile, the average maximum temperature for PP (P2) plastic type for each heat exchanger diameter variation is 393 °C, 372 °C and 348 °C, respectively. When fuel production takes place for each type of plastic and variation in heat exchanger diameter, the reactor temperature increases slowly until it shows Tmax. The maximum reactor temperature (Tmax) is inversely proportional to the diameter of the heat exchanger used. The larger the heat exchanger diameter, the lower the Tmax. Meanwhile, the smaller the heat exchanger diameter, the higher the Tmax. This can be seen from the speed of gas flow out of the reactor. When making fuel for each type of plastic, the larger the diameter of the heat exchanger, the lower the exit gas flow velocity. Meanwhile, the smaller the diameter of the heat exchanger used, the higher the exit gas flow velocity. The temperature of the pyrolysis reactor will affect the characteristics of the pyrolysis oil so that precise temperature control is important to optimize the pyrolysis results.

Increasing the pyrolysis temperature can affect the composition of the resulting product. At higher temperatures, some components can decompose further, producing different products. HDPE has shorter carbon chains and fewer hydrogen bonds, so it requires higher temperatures for decomposition into fuel oil.Testing of the physical properties of fuel oil resulting from the pyrolysis process of plastic waste was carried out three times, resulting from each type of plastic and variations in heat exchanger diameter. Table 2 shows data on the volume of petroleum steel material obtained from the pyrolysis process of 1 kg of plastic waste.

Table 2. Volume of fuel / 1 kg of plastic waste resulting from the pyrolysis process data

Sample	Volume (L)	Sample	Volume (L)
	0.55		0,60
P1D1	0.60	P2D1	0,65
	0.65		0,63
Average	**0.60**	**Average**	**0,63**
	0.70		0,75
P1D2	0.80	P2D2	0,85
	0.75		0,80
Average	**0.75**	**Average**	**0,80**
	0.88		0,90
P1D3	0.90	P2D3	1,10
	0.93		1,00
Average	**0.90**	**Average**	**1,00**

The volume of liquid fuel produced from 1 kg of both HDPE and PP materials is shown in table 2. 1 kg of HDPE plastic produces an average of 0.6 liters of liquid fuel at a heat exchanger diameter of ½ inch, 0.75 liters at a heat exchanger diameter of ¾ inch and 0.9 liters at a heat exchanger diameter of 1 inch. Meanwhile, PP plastic material produces fuel fluid of 0.63, 0.80 and 1.00 liters respectively. It can be seen that polypropylene (PP) plastic waste produces a higher volume of fuel compared to High Density Polyethylene (HDPE) plastic waste.

Figure 4. The relationship between the type of plastic and the diameter of the heat exchanger on the volume of fuel from plastic waste.

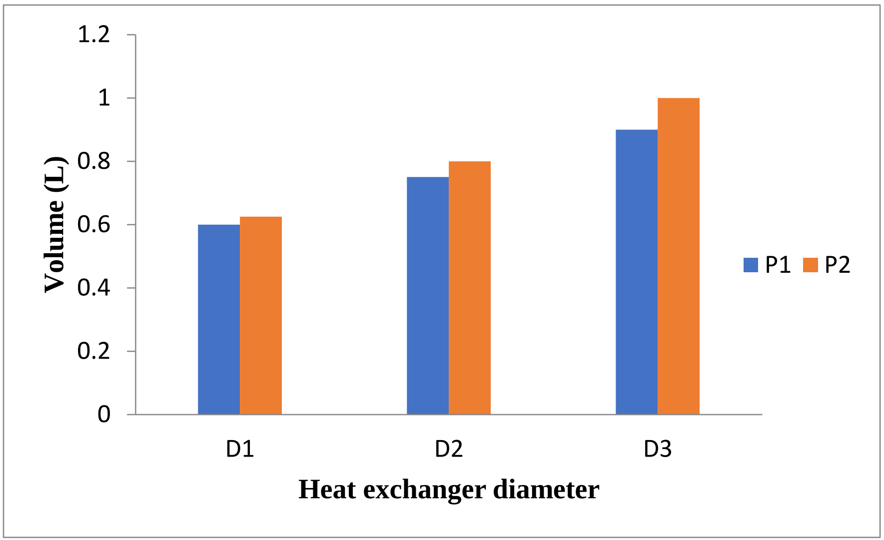


Figure 4 shows the volume of fuel oil produced using the plastic waste pyrolysis process for varying types of plastic and heat exchanger diameter. The average volume of fuel oil produced for the type of HDPE plastic (P1) for each variation of heat exchanger diameter respectively is 0 .6 L, 0.75 L and 0.9 L. Meanwhile, the average volume of fuel produced for PP (P2) plastic type for each heat exchanger diameter variation is 0.625 L, 0.8 L and 1 L, respectively.

The variations in heat exchanger diameter cause the volume of fuel oil produced to be different for each type of plastic. This is because the larger the heat exchanger diameter, the larger the cooling water contact area. So the heat transfer process gets better and more gas can be condensed (Alit and Mara, 2024). Meanwhile, the smaller the diameter of the heat exchanger, the smaller the contact area of the cooling water. So, the heat transfer process is smaller and less gas can be condensed. This can be seen from the heat exchanger exit gas temperature, the larger the heat exchanger diameter, the lower the exit gas temperature. The average exit gas temperature for HDPE plastic (P1) at heat exchanger diameters of 1/2 inch, 3/4 inch and 1 inch respectively is 95^{o}C, 81.98 ^{o}C and 53.37 ^{o}C. Meanwhile, the average exit gas temperature for PP (P2) plastic at heat exchanger diameters of 1/2 inch, 3/4 inch and 1 inch respectively is 92.85 ^{o}C, 73.38 ^{o}C and 45.75 ^{o}C.

The diameter of the heat exchanger affects the heat transfer efficiency during pyrolysis. The larger the diameter of the heat exchanger, the greater the surface area involved in heat transfer. The larger surface area allows more efficient heat transfer between the heating fluid and the raw material to be pyrolyzed. A larger diameter may allow for higher temperatures and better results. If the diameter is too small, the contact surface area will be limited, and heat transfer may be inefficient.

Polypropylene (PP) tends to produce a larger volume of fuel oil than high density polyethylene (HDPE). This is because PP has a longer carbon chain and more hydrogen bonds, so it is more easily decomposed during pyrolysis. At pyrolysis temperatures, PP decomposes more easily, resulting in more oil. Or in other words, the molecular structure of PP is simpler and is more easily broken down during pyrolysis compared to HDPE which has a more complex molecular structure and is more resistant to decomposition.

In addition, this can also be seen from the amount of heat absorbed by water during the process of making bajar materials. The greater the heat absorbed by the water, the better the heat transfer process will be. Thus, more fuel volume is produced during the fuel manufacturing process. The average value of heat absorbed by water for HDPE plastic (P1) at heat exchanger diameters of 1/2 inch, 3/4 inch and 1 inch respectively is 88.97 Watt/s, 150.12 Watt/s and 166.30 Watt/s. Meanwhile, the average value of heat absorbed by water for PP (P2) plastic type at heat exchanger diameters of 1/2 inch, 3/4 inch and 1 inch respectively is 90.27 Watt/s, 104.96 Watt/sand 122.47 Watt/s.

IV. CONCLUSION

Based on the results of the discussion above, it can be concluded as follows: Fuel oil produced by the pyrolysis process of plastic waste has different physical properties based on the type of plastic and variations in heat exchanger diameter. The process of making fuel oil from plastic waste using the pyrolysis process is the most effective for PP (P2) plastic waste with a heat exchanger diameter of 1 inch, that is, from 1kg of plastic waste an average volume of 1 L is obtained. Physical properties of fuel oil Maximum temperature of the reactor produced of each type of plastic waste decreases as the heat exchanger diameter increases. Meanwhile, the volume of the fuel produced increases as the heat exchanger diameter increases.

Conflict of interest

There is no conflict to disclose.

ACKNOWLEDGEMENT

The author would like to thank the Department of Mechanical Engineering, Faculty of Engineering, University of Mataram for the support of the facilities provided. Thanks are also expressed to colleagues who have contributed to the completion of this paper.

REFERENCES

[1]. Adoe, Dominggus G.H., Wenseslaus Bunganaen, Ika F. Krisnawi, Ferdyan A., Soekwanto., 2016, Pirolisis Sampah Plastik PP (Polyprophylene) menjadi Minyak Pirolisis sebagai Bahan Bakar Primer, LONTAR Jurnal Teknik Mesin Undana, Vol. 03, No. 01, April 2016, 17-26.

[2]. Ahmad Fudloilul A'la., 2022, Pengaruh Variasi Suhu Pada Proses Pirolisis Sampah Plastik LDPE Sebagai Bahan Bakar Alternatif, skripsi S1 Universitas Islam Malang Fakultas Teknik Progam Studi Teknik Mesin Malang.

[3]. Alfiando., Diego Alfin, Irwan Setyowidodo, Nuryosuwito., 2019, Perbandingan konsumsi bahan bakar minyak hasil pirolisis plastik HDPE bercampur serabut kelapa terhadap premium, Jurnal Mesin Nusantara, Vol. 1, No. 2, Januari 2019, Hal. 93-103.

[4]. Alit, Ida Bagus and I Made Mara , 2024, Characteristics physical and chemical properties of fuel from plastic waste for mineral water glasses, World Journal of Advanced Engineering Technology and Sciences, 2024, 11(01), 268–273

[5]. Dinas Kebersihan Kota Mataram, 2012, Komposisi Sampah Kota Mataram, Mataram.

[6]. Erlangga., Zeisha, Fahrul Rahmadi, dan Damian Andreas Lubis., 2023., Studi Nilai Massa Jenis Bahan Bakar Alternatif Minyak dari Proses Pirolisis Sampah Plastik HDPE (High Density Polyethylene) dan PET (Polyethylene Terephtalate), Jurnal Teknologi Lingkungan Lahan Basah, Vol. 11, No. 2, 2023: 540 – 547.

[7]. Harper, C.A., 2000, Modern Plastics Handbook, The McGraw-Hill Companies, Inc., United States of America.

[8]. Jahiding, M., E Nurfianti, E S Hasan , R S Rizki , Mashuni., 2020, Analysis of Pyrolysis Temperature Effect on Fuel-Oil Quality from Polypropilene Plastict Waste, Jurnal Gravitasi 19-1 (2020) 6-10.

[9]. Kurniawan, Eddy., Nasrun, 2014, Karakterisasi Bahan Bakar Dari Sampah Plastik Jenis High Density Polyethelene (HDPE) Dan Low Density Polyethelene (LDPE), Jurnal Teknologi Kimia Unimal 3 : 2 (November 2014) 41-52

[10]. Kadir, 2012, Kajian Pemanfaatan Sampah Plastik Sebagai Sumber Bahan Bakar Cair, Jurnal Ilmiah Teknik Mesin, ISSN : 2085-8817, Vol. 3, No. 2, Universitas Haluoleo, Kendari.

[11]. Mujiarto, Iman, 2005, Sifat dan Karakteristik Material Plastik dan Bahan Aditif, Staf Pengajar AMNI Semarang.

[12]. Nuryosuwito, Mokhamad Amirudin Ibnu Rosydi, Hesti Istiqlaliyah., 2020, Pemanfatan Sampah Plastik Jenis HDPE Menjadi Bahan Bakar Alternatif Proses Pyrolysis, Jurnal Mesin Nusantara, Vol. 3, No. 2, Desember 2020, Hal. 92-101.

[13]. Novarini, Sigit Kurniawan, Rusdianasari, Yohandri Bow., 2021, Kajian Karakteristik dan Energi pada Pirolisis Limbah Plastik Low Density Polyethylene (LDPE)., Jurnal Tek. Kim. Ling. 2021, 5 (1), 61-70.

[14]. Okariawan, I.D.K., Mara, I.M., dan Alit, I.B., 2011, Konversi Oli Bekas Menjadi Bahan Bakar Minyak Dengan Metode Pirolisis, Jurnal Teknik Mesin, ISSN 1411 – 9471, Vol.11, No.1, ITS, Surabaya.

[15]. Panda, A.K., 2011, Studies on Process Optimization for Production of Liquid Fuels from Waste Plastics. Thesis, Chemical Engineering Department National Institute of Technology, Rourkela.

[16]. Rodiansono, Trisunaryanti,W., dan Triyono, 2007, Pembuatan, dan Uji Aktivitas Katalis NiMo/Z pada Reaksi Hidrorengkah Fraksi Sampah Plastik menjadi Fraksi Bensin, BerkalaMIPA,17,2.

[17]. Santoso, J., 2010, Uji Sifat Minyak Pirolisis Dan Uji Performasi Kompor Berbahan Bakar Minyak Pirolisis Dari Sampah Plastik, Skripsi, Teknik Mesin Universitas Sebelas Maret, Surakarta.

[18]. Sari, Gina Lova., 2017, Kajian Potensi Pemanfaatan Sampah Plastik Menjadi Bahan Bakar Cair, Al-Ard: Jurnal Teknik Lingkungan Vol.3 No.1 - Agustus 2017, (06-13).

[19]. Wahyudi,I., 2001, Pemanfaatan Blotong Menjadi Bahan Bakar Cair dan Arang dengan Proses Pirolisis, Jurusan Teknik Lingkungan FTSP UPN "Veteran", Jatim.