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Characterization of Pyrolytic Oil Produced from Waste Plastic in Quezon City, Philippines using Non-Catalytic Pyrolysis Method

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Due to massive amount of waste plastics in different dumpsites, our community suffers and also the environment. Thus, affects nearby people with problems with plastic wastes. One of the processes to lessen these wastes is through pyrolysis of which fuel oil can be produced. The study involved the production of fuel oil from waste plastics taken from the Payatas dump site in Quezon City, Philippines. After thorough cleaning, the waste plastics were shredded thru mechanical means and underwent pyrolysis. Given the available thermal chamber facility in ITDI-DOST in Taguig City, Philippines, pyrolysis of waste plastics produced fuel oil in varying per cent yield from the different types of plastic. Characterization of the oil sample was conducted such as ash content, carbon residue, copper corrosion strip, flash point, pour point, sulfur, kinematic viscosity, specific gravity water and sediments that were based from the PNS/DOE QS 006-2005. The oil sample was analyzed using different laboratory tests following the methods of the American Society for Testing and Materials (ASTM). Using this standards, the analysis of the oil sample gave the positive results in comparison to the specifications set by the Philippine National Standard and was classified as fuel oil. Pyrolytic oil from waste plastic can be an alternative fuel source.

1. Introduction

Plastic production globally have increased significantly by almost 360 million tonnes (APME 2019) and a predicted 33 billion tonnes of plastic will circulate by the year 2050 (Rochman et al, 2013). Plastic waste in the landfill was about 38%, recyclables of 26% and only 36 % were being energy recovered (APME 2019). Because of plastics non-degradable nature a petroleum based product and possess long chains of hydrocarbons, making it hard to decompose (Sriningsih et al., 2014). Plastic waste problems have worsen year by year and with so many environmental methods were developed for the recycling of waste plastics, still millions of tonnes were dumped instead of just doing the recycling process (Mani et al, 2009).

The Philippines like any other Asian countries, has mismanaged plastic waste of around 1.88 million tonnes each year. A developing country has also a developing problem with regards to plastic waste that will eventually go directly to the ocean as a major pollution (Report 2017). One of the methods that was known today were recycling and energy recovery methods such as incineration, gasification and chemical processing (Syamsiro et al., 2014; Al-Salem et al., 2009). Recycling method was considered an alternative in solving the crowded landfill areas. But plastic recycling was proven difficult and labor intensive, and can also costly for separation methods (Kukreja 2019). A promising technique of plastic waste energy recovery was developed by converting the waste materials into fuel source (Begum et al., 2012). A more reliable and sustainable way was developed instead of reduction of the plastic waste by way of plastic recycling (Sharuddin et al, 2016).

Pyrolysis was introduced as a more sustainable method than recycling, for the conversion of the plastic waste and produced a liquid in high calorific values (Buah et al., 2007). Pyrolysis is a thermal degradation process in which a long chain of hydrocarbons were converted into shorter one. This requires ample amount of intense heat and pressure for a shorter span with the absence of oxygen gas and producing less harmful substance and emissions, and as compared to the emissions by incineration. With that good effect of using pyrolysis for thermally degrading plastic waste, so many researchers chose this methods to further the study in energy

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conversion. The produced oil in pyrolysis after meeting the suitable temperature of 500 ^oC, has high calorific value and liquid oil yield that can be used directly to power furnaces, boilers and diesel engines (Fakhrhoseini and Dastanian, 2013; Bridgwater et al, 2012). The pyrolytic oil produced depends in what type of plastic waste was being used in a pyrolyzer (Consea et al, 1994).

Therefore, in this study several types of plastic waste was used by category of resins types, such as (2,4) for polyethylene plastic bags, mixed plastic (7) for shampoo sachets and laminated plastics and polystyrene (6) for Styrofoam containers are pyrolyzed using a continuous type pyrolyzer which thermally degrades this waste plastics into pyrolytic oil.

Many research papers have been published regarding the potential of various types of waste plastics in pyrolysis processes for liquid production, but differs on the properties of the characterized fuel oil. The aim of this study is to characterized the produced pyrolytic oil from the several plastic waste in the Philippines, and determine if the produced pyrolytic oil complies with the standards set by Philippines National Standard for fuel oil which is the PNS/DOE QS 006-2005 and to be considered as an alternative fuel.

2. Methodology

2.1 Preparation of feedstock

Waste plastics were gathered from Payatas dumpsite in Quezon City, Philippines and sorted the different plastics based from resin number. Polyethylene (2,4) for plastic bags, mixed plastics (7) for shampoo sachets and laminated plastics while polystyrene (6) for Styrofoam containers. The feedstock were cleaned, shredded and air dried as shown in Figure 1, prior to pyrolysis in DOST-ITDI facility.

Each of the feedstock were weighed using a digital weighing scale of 2 kgs before pyrolysis.

Figure 1: Shredded waste plastic (PE, mixed plastic, and PS) from left to right.

2.2 Waste plastic pyrolysis

The pyrolyzer used in this study was a 5 KW muffle furnace to simulate the pyrolysis process as shown in Figure 2. It was a cylindrical continuous pyrolyzer with pre-heating chamber, a gas condenser and a water scrubber. The pyrolyzer was equipped with a rotating paddle by a gear-motor and the pre-heating chamber has an LPG burner with return gas from the condenser to provide heat. Pre-heating was set to temperature of 200 ^oC in which a significant weight loss was observed to start during pyrolysis of plastic (Cepeliogullar and Putun, 2013).

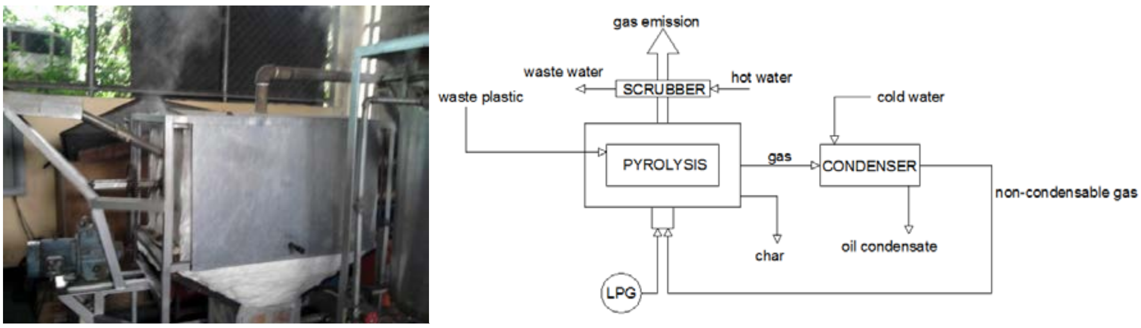

Figure 2: Pyrolyzer and the pyrolysis process.

Feedstock for resins numbers (2,4,7,6) were individually pyrolyzed. A residence time of 2 hrs per feedstock were used. After that time, the condensable gas will go to the condenser in which the condensable gas will be condensed to produce condensate oil (pyrolytic oil). The combustible non-condensable gas will be used to re-

power the pyrolyzer in addition with the liquefied petroleum gas (LPG). While the gas emissions, will go directly to the scrubber before releasing to the environment.
PE plastics degrade completely at temperature of 467 °C (Marcilla et al, 2005) while PS degrade completely at 300 °C. Mixed plastics were comprised of PE and PP (Donaj et al, 2012) while a related study of mixed plastic were composed of PE, PP and PS (Kaminsky et al, 1996). Polypropylene maximum degradation temperature is 400 °C (Ahmad et al, 2014). Percentage oil yield was monitored in temperatures (200 °C, 300 °C, 400 °C, and 500 °C. Up to a maximum temperature of 500 °C was used in all types of waste plastics in this study (Sharuddin et al, 2016).
Weight of 2 kgs, residence time of 2 hrs and 5 trials were used in the study to determine the maximum overall yield in each plastic type.

2.3 Oil collection

The pyrolytic oil produced in each plastic types based on resin number, was measured by weight using a digital weighing scale, as well as the weight of the feedstock used. To generate the overall percentage yield, Eq(1) was used. The output pyrolytic oil will be subjected to characterization to further determine its aptness as a fuel oil.

$$\%Yield = \frac{weight\ of\ produced\ oil}{weight\ of\ feedstock} \quad (1)$$

2.4 Characterization of pyrolytic oil

The collected pyrolytic oil undergo characterization in Department of Energy (Laboratory Division) to determine the suitability as fuel oil of the pyrolytic oil sample. The standard used in the characterization was PNS/DOE QS 006-2005 for Bunker Fuel Oil based on the standard set by the Philippines for liquid fuels. Table 1, is the PNS standards used including its American Society for Testing and Materials (ASTM) number in each specific laboratory test.
Sulfur content in fuel oil was very important to determine its volatility. Flash point on the other hand determines the lowest temperature in which the vapors will ignite when subjected to open flame. Meanwhile, ash content in fuel oils should be generally low. Fuel oil viscosity will determine how the liquid oil will flow and water and sediments are the impurities. These five properties are significant in determining the overall quality of the produced pyrolytic oil set by the Philippine National Standard (PNS) for fuel oil.

Table 1: PNS/DOE QS 006-2005 for Bunker fuel oil

Property	Limit			Test Method
	BFO 3.0*	BFO 2.0**	BFO 1.0**	
Sulfur, % mass, max	3.0	3.0	3.0	ASTM D4294
Flash Point, (Pensky-Martens) °C, min	60.0	60.0	60.0	ASTM D93 ASTM D482
Ash, % mass, max	0.20	0.20	0.20	
Viscosity, mm^2/s @ 50 °C, max	300	200	200	ASTM D445
Water and Sediments, % Volume, max	1.0	1.0	1.0	ASTM D1796

*BFO 3 is considered as regular grade of bunker fuel oil
**BFO 1 and 2 are considered as special grade of bunker fuel oils

3. Results and Discussion

3.1 Effects of temperature in the percentage oil yield

During pyrolysis, temperature was set from 200 °C, 300 °C, 400 °C, and 500°C in each of the feedstock used based on resin numbers. Temperature play a vital role in processing the reaction mechanism for the pyrolysis process. Percentage oil yield on the other hand, was the output in the pyrolysis process, and was based on the Eq(1). Temperature and percentage oil yield shows a positive trendline for PE, mixed plastic and PS. Increasing the temperature will also increase the percentage oil yield. Between temperatures 200 °C, 300 °C, 400 °C, and 500°C, PS plastic possess the highest weight reduction. If liquid yield was preferred, lower temperature in the range of 300 – 500 °C was recommended (Sharuddin et al, 2016).

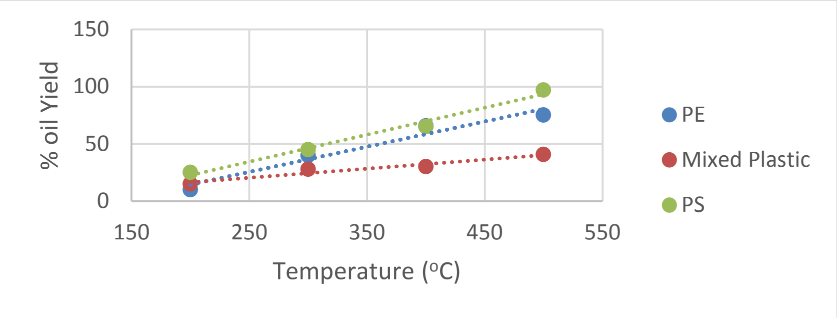

Figure 3: Relationship of percentage oil yield with temperature.

Table 2: Correlation coefficient between temperature and percentage oil yield

Temperature	Plastic types		
	PE	Mixed plastic	PS
200	10	15	25
300	40	28	45
400	65.5	30.25	65
500	75	40.75	90
Correlation coefficient (%)	97.78	97	99

Table 2, presents the Pearson correlation coefficient between temperature and percentage oil yield. A strong positive correlation were evident in PE, mixed plastic and PS with correlation coefficient of 97.78 %, 97 %, and 99%, respectively.

3.2 Maximum pyrolytic oil yield

Maximum pyrolytic oil yield was determined in order to analyze the factors surrounding the highest value produced. Temperature can have the full control on the degradation of the specific feedstock used. Using Eq(1), in determining the overall percentage yield in the pyrolysis of PE, mixed plastic and PS waste plastics, table 3 shows the maximum % oil yield with maximum set temperature of 500°C, residence time of 2 hrs in 5 trials each per plastic type. The mixed plastic showed 40.75 % oil yield, which is slight lower than the produced oil with a yield 48.4 wt%, maybe because the reactor used was a fluidized bed in temperature of 730°C (Kaminsky et al, 1996). The % oil yield obtained was also near the study conducted with 46.6 %wt oil yield (Demirbas, 2004).

Pyrolysis of HDPE (2) produced a 75 %wt oil yield which was near the produced oil of 80.88 %wt (Ahmad et al, 2014) which uses a micro steel reactor, which was also comparable to a study (Kumar and Singh, 2011) which produced a 79.08 %wt oil yield which uses a semi-batch reactor in maximum temperature of 550°C. While pyrolysis of LDPE (4) produced a high oil yield of 93.01 %wt (Marcilla et al, 2005). Another study conducted produced a 95 %wt oil yield, using a fixed bed reactor (Bagri and Williams, 2001).

PS pyrolysis produced 90 %wt and was the highest among the 3 plastic type used. The % oil yield produced was near the %wt oil yield of 97% using a batch type reactor with maximum temperature of 500°C (Onwudili et al, 2009).

Table 3: Maximum Pyrolytic Oil yield

Plastic Type	Oil Yield (%wt)
PE (2,4)	75
Mixed Plastic (7)	40.75
PS (6)	90

3.3 Characterization results for pyrolytic oil

Table 4 shows the laboratory analysis/test report of the different waste plastic types used in the study. Based on properties based on standards set by PNS/DOE QS 006-2005, PE has the highest sulfur and ash content

with 0.89% and 0.05 %, respectively. Mixed plastic has a very flammable property of <40^{o}C, highest viscosity of 2.57 mm^2/s and highest water and sediments component of 0.1 % by volume as compared to PE and PS.
Results showed in table 5 that all pyrolytic oil produced from the 3 types of plastics were under BFO 1.0 which is a special grade of bunker fuel oil. This results was justified in utilizing pyrolysis oil from plastic as a fuel in diesel engines as well as powering boilers, kilns etc (Kaimal and Vijayabalan, 2015; Mani et al, 2011).

Table 4: Summary of Results based on PNS/DOE QS 006-2005

Test	PE (2,4)	Mixed (7)	PS (6)
Sulfur, % mass, max	0.890	0.005	0.009
Flash Point, (Pensky-Martens) ^{o}C, min	80	<40	42
Ash, % mass, max	0.05	0.02	0.03
Viscosity, mm^2/s @ 50 ^{o}C, max	0.87	2.57	2.19
Water and Sediments, % Volume, max	<0.05	0.1	<0.05

*BFO 3 is considered as regular grade of bunker fuel oil
**BFO 1 and 2 are considered as special grade of bunker fuel oils

Table 5: BFO number based on PNS/DOE QS 006-2005

Plastic type	BFO Number
PE	1.0
Mixed plastic	1.0
PS	1.0

4. Conclusions

In this study, pyrolysis was used in thermal degrading PE, mixed plastic and PS. Percentage oil yield by weight was determined using set parameters of 500^{o}C, residence time of 2 hrs and conducted 5 trials each types of the plastics used. Polystyrene pyrolysis produced the highest percentage oil yield of 90% while mixed plastic pyrolysis has the lowest with oil yield of 40.75 %wt. The difference in the percentage oil yield from the other studied plastic pyrolysis was affected by the type of reactor and temperature used in the process. An increase in the temperature will have a significant increase in the percentage oil yield.
Characterization of the produced pyrolytic oil was determined by using PNS/DOE QS 006-2005 standards, and showed that all the used plastics in this study were considered as a special grade of bunker fuel 1.0 using the property requirements for sulphur content, flash point, ash content, viscosity and water and sediments. It was concluded that the pyrolytic oil from PE, mixed plastic and PS can be an alternative fuel source.
Industries using bunker/fuel oil to power their boilers, kiln, etc, should consider using pyrolytic oil from waste plastic to lessen their fossil fuel consumption and a study on the overall refinement of the pyrolytic oil from plastic waste was recommended in order for the oil be as an alternative in fuelling diesel and gasoline engines.

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References

Ahmad I., Khan M.I., Khan H., Ishaq M., Tariq R., Gul K., Ahmad W., 2014, Pyrolysis study of polypropylene and polyethylene into premium oil products, Int J Green Energy, 12:663–71.
Al-Salem S.M., Lettieri P., Baeyens J., 2009, Recycling and recovery routes of plastic solid waste (PSW): a review, Waste Manage, 29 (10), 2625–2643.
Bagri R., Williams P.T., 2001, Catalytic pyrolysis of polyethylene, J Anal Appl Pyrol, 63:29–41.
Begum S., Rasul M., Akbar D., 2012, Identification of an appropriate alternative waste technology for energy recovery from waste through multicriteria analysis, world academy of science, Eng. Technol, 63, 944–949.

Big Western brands polluting oceans with cheap plastic in Philippines: REPORT. 2017,. http://www.theborneopost.com/2017/09/22/big-western-brands-polluting-oceans-with-cheap-plastic-in-philippines-report/. Accessed 11.02.2020

Bridgwater A.V., 2012, Biomass & Bioenergy, 38 68.

Buah W.K., Cunliffe A.M., Williams P.T., 2007, Characterization of products from the pyrolysis of municipal solid waste, Process Saf. Environ. Prot., 85 (5), 450–457.

Cepeliogullar O., Putun A.E., 2013, Utilization of two different types of plastic wastes from daily and industrial life, In: Ozdemir C, Sahinkaya S, Kalipci E, Oden MK, editors. ICOEST Cappadocia 2013. Turkey: ICOEST Cappadocia; p. 1–13.

Consea J.A., Font R., Marcilla A., Garcia A.N.,1994, Pyrolysis of polyethylene in a fluidized bedreactor, Energy Fuel 8, 1238–1246.

Demirbas A., 2004, Pyrolysis of municipal plastic wastes for recovery of gasolinerange hydrocarbons, J Anal Appl Pyrol, 72:97–102.

Donaj P.J., Kaminsky W., Buzeto F., Yang W., 2012, Pyrolysis of polyolefins for increasing the yield of monomers' recovery, Waste Manage, 32:840–6.

Fakhrhoseini S.M., Dastanian M., 2013, Predicting pyrolysis products of PE, PP, and PET using NRTL activity coefficient model, Hindawi Publishing Corporation, p. 1–5.

Kaimal V.K., Vijayabalan P., 2015, A detailed study of combustion characteristics of a DI diesel engine using waste plastic oil and its blends, Energy Convers. Manage, 105, 951–956.

Kaminsky W., Schlesselmann B., Simon C.M., 1996, Thermal degradation of mixed plastic waste to aromatics and gas, Polym Degrad Stab, 53:189–97.

Kukreja R., 2009, Advantages and disadvantages of recycling, Conserve Energy Future.

Kumar S., Singh R.K., 2011, Recovery of hydrocarbon liquid from waste high density polyethylene by thermal pyrolysis, Braz J Chem Eng, 28:659–67.

Mani M., Nagarajan G., Sampath S., 2011, Characterization and effect of using waste plastic oil and diesel fuel blends in compression ignition engine, Energy 36, 212–219.

Mani M., Subash C., Nagarajan G., 2009, Performance, emission and combustion characteristics of a DI diesel engine using waste plastic oil, Appl. Therm. Eng., 29 2738–2744.

Marcilla A., García-Quesada J.C., Sánchez S., Ruiz R., 2005, Study of the catalytic pyrolysis behaviour of polyethylene–polypropylene mixtures, J Anal Appl Pyrol ,74:387–92.

Onwudili J.A., Insura N., Williams P.T., 2009, Composition of products from the pyrolysis of polyethylene and polystyrene in a closed batch reactor: effects of temperature and residence time, J Anal Appl Pyrol, 86:293–303.

Plastics Europe, Plastics – the Facts 2019 – An Analysis of European Plastics Production, Demand and Waste Data, ed, 2019, Brussels, Belgium :Plastics Europe (the Association of Plastics Manufacturers in Europe, APME).

Rochman C.M., Browne M.A., Halpern B.S., Hentschel B.T., Hoh E., Karapanagioti H.K., Rios-Mendoza L.M., Takada H., Teh S., Thompson R.C., 2013, Policy: classify plastic waste as hazardous, Nature 494169–171.

Sharuddin S.D.A., Abnisa F., Wan Daud W.M.A., Aroua M.K., 2016, A review on pyrolysis of plastic wastes. Energy Conversion and Management, 308-326.

Sriningsih W., Saerodji M.G., Trisunaryanti W., Triyono, Armunanto R., Falah I.I., 2014, Fuel production from LDPE plastic waste over natural zeolite supported Ni, Ni-Mo, Co and Co-Mo metals, Procedia Environ. Sci, 20, 215–224.

Syamsiro M., Saptoadi H., Norsujianto T., Noviasri P., Cheng S., 2014, Fuel oil production from municipal plastic wastes in sequential pyrolysis and catalytic reforming reactors, Energy Procedia, 47, 180–188.