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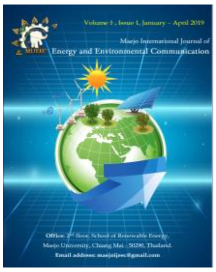

ARTICLE

Effect of ultraviolet light on the degradation of Low-Density and High-Density Polyethylene characterized by the weight loss and FTIR

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ABSTRACT

In this study, the research was made to understand the knowledge widely related to the degradation process of polyethylene polymer. The mode of treatment that involves in the degradation process of polyethylene is physical treatment while the method of degradation used is photo-degradation of UV light. By using the physical treatment of UV irradiation light, it helps by affecting the bonding that holds the polymer together to break and weakens the plastic. From the result obtained in FTIR and SEM analysis, in FTIR spectrum of LDPE shows higher transmittance compared to FTIR spectrum of HDPE both UV-treated for 30 days. This indicates the high transmittance have few bonds to absorb light in the LDPE sample, low transmittance in HDPE sample means has high population of bonds which have vibrational energies corresponding to the incident light. For SEM result, the polyethylene for LDPE plastic sheet shows the best results for degradation and managed to reduce the weight loss at 87.5% compared to HDPE plastic which at 21.6%.

1. Introduction

The global production and widespread consumption of plastics have been dramatically increasing from years to years (Govindan et al., 2018). The plastic materials are strong, durable and very slow to degrade which resulted to become waste(Bhuyar et al., 2020). The littering, over-consumption and disposal of plastics have resulted in serious environmental pollution (Zhao et al., 2018). Most of the plastics such as polyethylene (PE), polystyrene (PS) and polypropylene (PP) are majorly plastic waste found in landfills. These plastics affect the ecosystem and environmental with increasing accumulation of plastic waste. Plastics is a material in which the applications are widely used. The production of plastics always growth faster due to low cost, reusable and lightweight. Plastic is hard to degrade and takes many years to naturally degrade. It is very crucial to know the structure of polymer also the characteristics which change the life span of the material with environmental factors (Moharir and Kumar, 2019).

The disposal of plastic waste is usually done by using traditional methods such as landfill, incineration and recycling. The disadvantages of these available methods are the process is not effective and efficient for the disposal of plastic waste. Therefore, the alternatives methods for disposing the plastic waste still be discovered (Moharir and Kumar, 2019).

In this study, polyethylene is chosen as a type of plastic that is used for the experiment. Polyethylene which is the most type of plastic used in the industry also it is a stable polymer that contains long chains of ethylene monomers (Tokiwa et al., 2009). Polyethylene composed of low-density polyethylene (LDPE) and high-density polyethylene (HDPE). LDPE is softer plastic and melts at low temperature. HDPE is a tough plastic material, low flexibility, rigid, resistant to ultraviolet rays and can withstand high temperature.

The main purpose of this study is to degrade the level of polyethylene by UV treatment using FTIR analysis and SEM analysis. SEM analysis was used to observe their surface characteristics. This study is aimed at the FTIR to observe the further plastic degradation level that can be achieved. Polyethylene (PE) was found as the most common plastic types in municipal solid waste and the degradation was experimented and conducted by FTIR analysis (Tribedi & Dey, 2017).

2. Methodology

2.1 Selection of Polyethylene

Plastic samples were collected and used to study the degradation of the plastic. The type of plastic samples that will be used is polyethylene (PE). The selection of plastic samples is based on the low-density polyethylene (LDPE) and high-density polyethylene (HDPE) only. The plastic samples that have been collected from LDPE and HDPE are from different sources. The example of a plastic sample used for LDPE is plastic packaging while the example of a plastic sample used for HDPE is garbage plastic. Then, the collected plastic samples were brought to the laboratory and labelled with the LDPE and HDPE.

2.2 UV Irradiation Treatment

The samples of LDPE and HDPE were cut into the same sizes of 5 cm x 5 cm square diameter and placed into two different aluminium foil. Then, the samples were placed in the Laminar Air Flow (LAF) under UV light of wavelength of 253.7nm. The plastic sheet of LDPE and HDPE under UV irradiation light were carried out for the range of every 5 days up until 30 days. LDPE and HDPE sheet were exposed to UV irradiation light for 120 h at 30°C for every 5 days up until 30 days inside the laminar air flow. The distance between the plastic samples and the UV lamp was kept at 30 cm (Tribedi & Dey, 2017). By exposing the polyethylene of LDPE and HDPE sheet to UV light under controlled lab condition, it helps to break the chemical bonding peptide between the polymer chains of plastic. After that, the plastic sheet of LDPE and HDPE which exposed directly under UV irradiation light for 24 hours were monitored and observed for 15 days and 30 days. Both LDPE and HDPE sheet that undergoes UV-treated will be compared with the plastic sheet of LDPE and HDPE untreated UV (control).

2.3 Weight loss Determination

For the plastic sheet of LDPE and HDPE untreated UV were required as control. The plastic sheet of LDPE and HDPE control were measured by using the electronic balance instrument for the initial weight as shown in Figure 3.4. The weight for the plastic sheet of LDPE and HDPE is used in the unit of milligram (mg). Then, the plastic sheet of LDPE and HDPE under UV-treated for 15 days and 30 days were collected and were measured for the final weight. The control of LDPE and HDPE sheet were required to compare with the final weight of LDPE and HDPE sheet (Tribedi & Dey, 2017).

The weight loss of the plastic sheets before and after the experiment are used as a parameter for rate of degradation with some other important parameters. The loss of weight is the indicating parameter of degradation of plastic sheet. To quantify the level of degradation of LDPE sheet, the weight loss of both UV-treated and UV-untreated LDPE sheet was measured. Hence, the weight of plastic sheets before and after the degradation process is the necessary parameter to considered (Moharir and Kumar, 2019).

2.4 FTIR Analysis

The plastic sheet of LDPE and HDPE were analysed using the instrument of Fourier transform infrared spectroscopy (FTIR) brand Perkin Elmer, Model Spectrum 100. The plastic sheet of LDPE and HDPE was scanned at room temperature from 400 to 4000 cm^{-1} (wavelength) using FTIR for every 5 days up until 30 days of UV treatment (Bhuyar et al., 2019). Each sample was repeated three times for the confirmation of the spectrum (Tribedi and Dey, 2017). After that, the data spectrum of the plastic sheet of LDPE for 30 days were compared with the data spectrum of the plastic sheet of HDPE for 30 days.

Nomenclature and Abbreviation

FTIR	Fourier Transform Infrared Spectroscopy
HDPE	High Density Polyethylene
LAF	Laminar Airflow
LDPE	Low Density Polyethylene
SEM	Scanning Electron Microscopy
UV	Ultraviolet

2.5 Scanning Electron Microscopy

The plastic sheet of LDPE and HDPE were analysed using Scanning electron microscope (SEM) brand FEI QUANTA 450. The plastic sheet of UV-treated LDPE and HDPE were analyzed using (SEM) for 0 days (control), 15 days and 30 days. After that, the SEM image of a plastic sheet of LDPE for 0 days (control), 15 days and 30 days were compared with the SEM image of a plastic sheet of UV-treated HDPE for 0 days (control), 15 days and 30 days in terms of surface of both LDPE and HDPE sheet.

3. Results and Discussion

3.1 Selection of Polyethylene

The samples of plastic were chosen based on the type of polyethylene that are LDPE and HDPE were used to compare the degradation between it.

3.2 UV Irradiation Treatment

3.2.1 Low density Polyethylene

Based on the result shown above, the LDPE sheet of UV-treated in Figure 1 shows the brittle fracture process that is caused by the UV irradiation light which lead to the crack of the plastic sheet. Meanwhile, the LDPE sheet of untreated UV Figure 1(a) shows the smooth surface of the plastic sheet. The LDPE sheet after 30 days of UV-treated is more fragile and completely broken up into small parts compared to the LDPE sheet after 15 days of UV-treated. The longer the UV treatment applied to the LDPE sheet, the more crack and fragile the plastic sheet. Furthermore, the LDPE sheet resulted in a brittle and stress cracking surface because they are not UV stable. The UV irradiation light helps to accelerate the reaction towards the LDPE sheet (Elgert, 2005).

The plastic sheet thickness indicates its strength where the thinner the sheet, the faster will be the rate of degradation. This is one of the most important parameters need to be considered for degradation studies of plastic sheet (Moharir and Kumar, 2019).

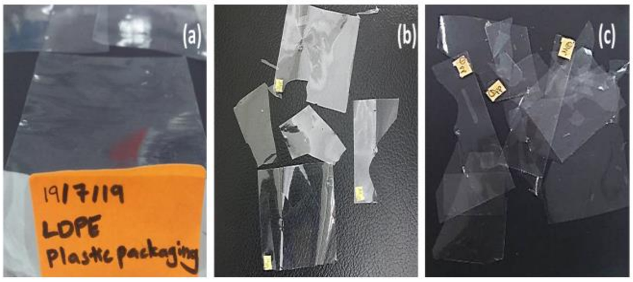

Figure 1. (a) The LDPE sheet (control), (b) The LDPE sheet after 15 days of UV treatment, (c) The LDPE sheet after 30 days of UV treatment

3.2.2 High Density Polyethylene

Based on the result shown above, the HDPE sheet of UV-treated in Figure 2 shows the rough surfaces also cause changes such as more roughness in Figure 4 shows the crack fracture process that is caused by the UV irradiation light which lead to the crack of the plastic sheet. Meanwhile, the HDPE sheet of untreated UV in Figure 2(a) shows the smooth surface of the plastic sheet. The HDPE sheet after 30 days of UV-treated is more crack and tear up into small parts compared to the HDPE sheet after 15 days of UV treated. The longer the UV treatment applied to the HDPE sheet, the more crack the HDPE sheet will be. Furthermore, the HDPE sheet resulted in a stress cracking surface because they are not UV stable. The UV irradiation light helps to accelerate the reaction towards the HDPE sheet (Elgert, 2005).

The plastic sheet thickness indicates its strength where the thicker the sheet, the more will be the strength and also thicker sheet will degrade slowly. This is one of the most important parameters need to be considered for degradation studies of plastic sheet (Moharir and Kumar, 2019).

Figure 2. (a) The HDPE sheet (control), (b) The HDPE sheet after 15 days of UV treatment, (c) The HDPE sheet after 30 days of UV treatment

3.2 Weight loss Determination

Based on the results shown in Table 1, the weight of UV-treated polyethylene and the percentage of weight loss for UV-treated polyethylene has been summarized in Figure 3. In The trendline weight of UV-treated LDPE for 30 days shows more weight loss compared to the trendline weight of UV-treated HDPE for 30 days.

Table 1. The weight loss of UV-treated polyethylene

No.	Sample name	Sample type	Initial weight (mg)	15 days weight (mg)	Final weight (mg)	Weight loss (mg)	Weight loss (%)
1	Plastic packaging	LDPE	100.3	95.0	12.5	87.8	87.5
2	Garbage plastic	HDPE	142.9	127.5	112.1	30.8	21.6

The percentage of weight loss (%) of the polyethylene was determined by this formula:

% Weight Loss = [(Initial Weight-Final weight)/Initial weight] x 100 %

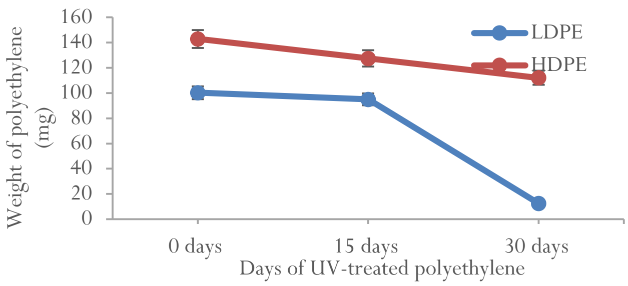

Figure 3. The weight of UV-treated polyethylene

In Figure 4, the percentage of weight loss for UV-treated LDPE sheet was 87.5% while the weight loss for UV-treated HDPE sheet was 21.6%. This shows that the percentage weight loss for UV-treated LDPE is higher than the weight loss for UV-treated HDPE. Furthermore, this means that the UV-treated LDPE sheet were easily degraded under UV irradiation light compared to the UV-treated HDPE sheet. The weight loss from initial to final weight indicates the level of both LDPE and HDPE degradation (Tribedi and Dey, 2017).

Besides, LDPE has a low-density which lead to easy degradation compared to the HDPE which has a high-density. Density is an important parameter because it shows the information about the intrinsic strength of the construction to be created as in the case of flax reinforcement, LDPE is the best choices due to the low density since its purpose of the material is to produce a composite that is as light as possible (Grigore, 2017).

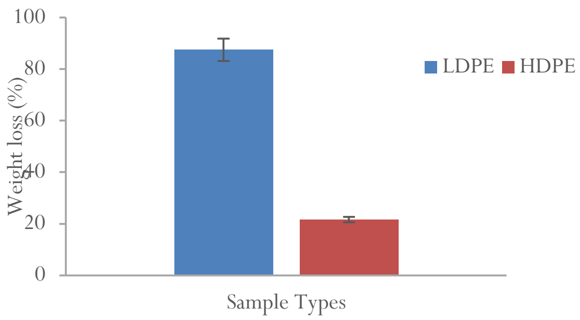

Figure 4. The percentage of weight loss of UV-treated polyethylene

3.2 FTIR Spectroscopy

3.3 3.4.1 Low Density polyethylene

The analysis of FTIR spectrum peaks was measured and presented in Transmittance mode by the FTIR instrument as shown in Figure 5. Generally, for qualitative purposes used Transmittance (%T). The plastic sheet of LDPE was scanned at room temperature from 400 to 4000 cm^{-1}. For FTIR spectrum of LDPE UV-treated for 30 days shows higher transmittance compared to other FTIR spectrum of LDPE UV-treated for 0 days, 5 days, 10 days, 15 days, 20 days and 25 days. LDPE UV-treated for 30 days has higher transmittance and few bonds to absorb that "color" light in the LDPE sample while LDPE UV-treated for 0 days has lower transmittance and high population of bonds which have vibrational energies corresponding to the incident light. Besides, transmittance can be equal to zero that means the sample completely blocks by the infrared. FTIR spectra of LDPE were obtained to determine molecular changes before and after UV irradiation (Sadaqat et al., 2016).

A background spectrum must be measured because there needs to be a relative scale for the absorption intensity. Normally a background spectrum is a measurement with no sample in the beam. This can be compared to the measurement with the sample in the beam to determine the percent transmittance (Thermo Fisher Scientific Inc., 2013).

3.4.2 High density polyethylene

The analysis of FTIR spectrum peaks was measured and presented in Transmittance mode by the FTIR instrument as shown in Figure 6.

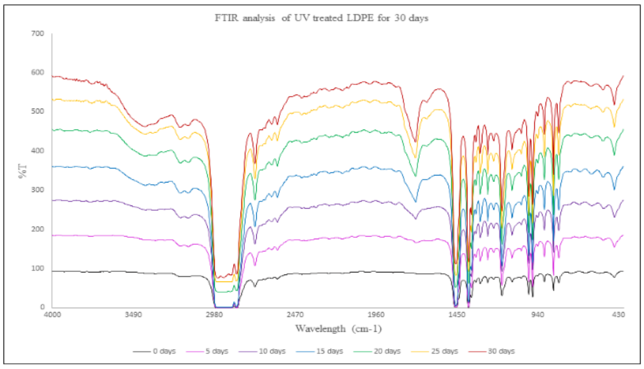

Figure 5. The Graph of transmission infrared spectrum of UV-treated LDPE for 30 days

Generally, for qualitative purposes used Transmittance (%T). The plastic sheet of HDPE was scanned at room temperature from 400 to 4000 cm^{-1}. For FTIR spectrum of HDPE UV-treated for 30 days shows higher transmittance compared to other FTIR spectrum of HDPE UV-treated for 0 days, 5 days, 10 days, 15 days, 20 days and 25 days.

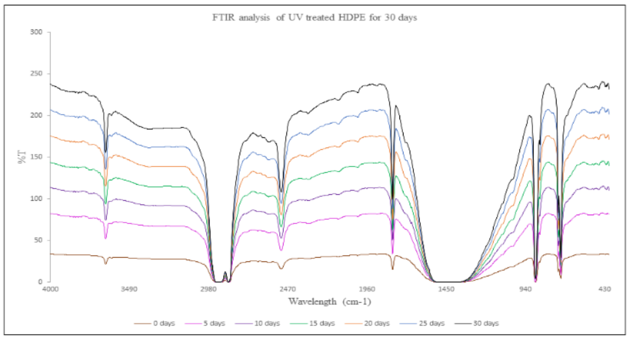

Figure 6. The Graph of transmission infrared spectrum of UV-treated HDPE for 30 days

HDPE UV-treated for 30 days has higher transmittance and few bonds to absorb that "color" light in the HDPE sample while HDPE UV-treated for 0 days has lower transmittance and high population of bonds which have vibrational energies corresponding to the incident light. Besides, transmittance can be equal to zero that means the sample completely blocks by the infrared. FTIR spectra of LDPE were obtained to determine molecular changes before and after UV irradiation (Sadaqat et al., 2016).

A background spectrum must be measured because there needs to be a relative scale for the absorption intensity. Normally a background spectrum is a measurement with no sample in the beam. This can be compared to the measurement with the sample in the beam to determine the percent transmittance.

3.4 Scanning Electron Microscope analysis

Based on the result shown above, the image under SEM of UV-treated LDPE sheet in Figure 7(c) shows the scratch and crack surfaces while in Figure 7(b) shows the LDPE fragile sample are broken into many small parts. Meanwhile, the LDPE sheet of untreated UV in Figure 7(a) shows the smooth surface of the plastic sheet. The LDPE sheet after 30 days of UV-treated shows more fragile condition compared to the LDPE sheet after 15 days of UV-treated.

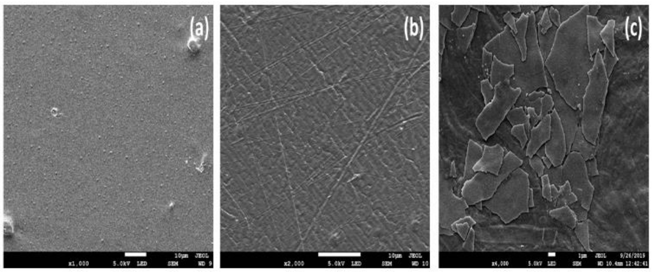

Figure 7. (a) LDPE control image under SEM at 1000X magnification, (b) LDPE sample after 15 days UV-treated image under SEM at 2000X magnification, (c) LDPE fragile sample after 30 days UV-treated image under SEM at 4000X magnification

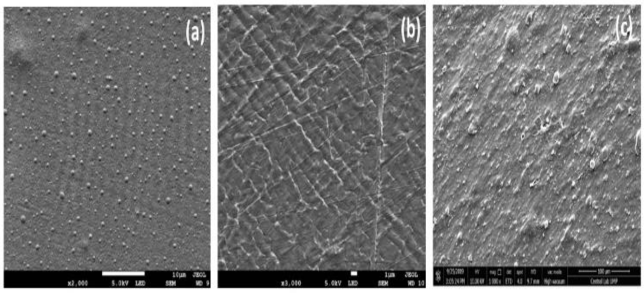

Figure 8. (a) HDPE control image under SEM at 2000X magnification, (b) HDPE sample after 15 days UV-treated image under SEM at 3000X magnification, (c) HDPE sample after 30 days UV-treated image under SEM at 1000X magnification

Based on the result shown above, the image under SEM of UV-treated HDPE sheet in Figure 8(c) shows the scratch surfaces while in Figure 8(b) shows the presence of rough, cracks and holes formation surfaces. Meanwhile, HDPE sheet of untreated UV in Figure 8(c) shows the smooth and plane surface of the plastic sheet. The HDPE sheet after 30 days of UV-treated shows more roughness and holes formation condition compared to the HDPE sheet after 15 days of UV-treated (Sadaqat et al., 2016).

The SEM image showed the alteration in surface topography between UV-treated and UV-untreated LDPE and HDPE sheet which in UV treatment caused some cracks to occur in HDPE sheet (Tribedi & Dey, 2017). In SEM, the scanning frequencies are required to obtain sharp and clear 3-D images of polymer surfaces. The measurements were performed by using an acceleration voltage of 5.0 kV and 10 kV as for HDPE polymers. The magnification of SEM can be achieved from 40X up to 250,000X ("Scanning Electron Microscopy & EDX Analysis," n.d.).

4. Conclusion

In this study, the types of polyethylene plastic which consists of LDPE and HDPE were collected and used in this experiment. By using the physical treatment of UV irradiation light, it helps by causing the bonding that holds the polymer together to break and also weakens the plastic. The UV irradiation light helps to accelerate the reaction towards the LDPE and HDPE sheet. Besides, the polymers will be affected to some degree of exposure to UV radiation. From the result obtained in FTIR and SEM analysis, in FTIR spectrum of LDPE UV-treated for 30 days shows higher transmittance compared to FTIR spectrum of HDPE UV-treated for 30 days. This means the high transmittance have few bonds to absorb that "color" light in the LDPE sample, low transmittance in HDPE sample means has high population of bonds which have vibrational energies corresponding to the incident light. For SEM result, the polyethylene for LDPE plastic sheet shows the best results for degradation and managed to reduce the weight loss at 87.5% compared to HDPE plastic which at 21.6%. Furthermore, the LDPE sheet turned more fragile than HDPE sheet after UV-treated because LDPE are higher UV unstable compared to HDPE which are low UV stable and due to having different polymer structure.

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