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LDPE Film Waste Treatment into Liquid Fuel using Catalytic Cracking

Jenny N.M.Soetedjo[1,a], Michael Osborn[1,b], Lucas Adriel Setiawan[1,c],
Farhan Azka Fadillah[1,d], Felicia Tjandra[1,e], Kevin Frendy Mulya[1,f],
Nehemia Rariel E.[1,g], Tedi Hudaya[1,h*]

[1]Department of Chemical Engineering, Parahyangan Catholic University, Jl. Ciumbuleuit 94, Bandung, 40141, Indonesia

*Corresponding author: [h]t.hudaya@unpar.ac.id,
[a]jenny.novianti@unpar.ac.id, [b]michaelosborn7974@gmail.com, [c]lucasadrielsetiawan@gmail.com,
[d]fazka17@gmail.com, [e]feliciatjandra9@gmail.com, [f]kevinfren97@gmail.com,
[g]nehemiaevan10@gmail.com

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Abstract. Plastic industry development has increased the amount of plastic waste, including LDPE plastic film, therefore LDPE waste processing becomes essential, such as thermal or catalytic cracking. Cracking is the breakdown of complex hydrocarbons into simple and commercial hydrocarbons (C_3-C_{40}). The catalytic cracking is preferred due to lower temperatures, which is 200-300°C instead of 500-700°C. In this study, catalyst selection, acid impregnation of catalyst, catalyst loading (wt%), N_2-gas-purging, feed-to-solvent weight-ratio, temperature, and reaction time were studied to determine the most suitable process condition to obtain the highest liquid fraction. In this study, the catalytic cracking was conducted at 20 bar with kerosene as solvent, with and without N_2-gas-purging at several temperatures (265 and 295°C), solvent-to-feed weight-ratios (5:1 and 4:1), catalyst types (bentonite, SiO_2 and ZSM-5), catalyst loading (wt%) (1.0wt%; 5.0wt%; 7.0wt%; 9.0wt%; 10.0wt%), and reaction time (1-3 hours). The best results were with N_2-gas-purging using 10.0wt%-bentonite in (5:1) solvent-to-feed weight-ratio for 1 hour at 295°C produced 54.9wt% of liquid fraction and without N_2-gas-purging at 265°C produced 54.5wt% of liquid fraction, indicating the possibility of N_2-gas-purging exclusion in future studies. Additionally, this study has promoted bentonite as a potentially viable catalyst for LDPE plastic waste catalytic cracking.

Introduction

Plastic pollution has become one of the world's major problems. A World Bank study found that the world's population generates 1.3 billion metric ton of waste every year, with plastic being one of the largest contributors [1]. Human life is closely related to the use and production of plastics and rapid population growth is a problem. As can be seen in the report "Evaluating Scenarios Toward Zero Plastic Pollution", the plastic production in 1950 was 2.3 million metric ton, which soared to 448 million metric ton in 2015 and is projected to reach up to 1.3 billion metric ton by 2040 [2]. The increase in plastic pollution occurred because of single-use culture, where plastic is often used once and then thrown away and is not managed properly. According to the publication by the United Nations Environment Program [3], it was found that 50% of the world's plastic pollution consists of single-use plastics. Examples of single-use plastics include plastic wrap, plastic bottles, plastic bags, plastic straws, and plastic cutlery [3]. Single-use plastics are generally composed of LDPE (low density polyethylene) and it is estimated that the world's population use one to five trillion plastic bags [3,4].

There are many known methods for processing LDPE, such as land filling, incineration, mechanical recycling, and thermo-chemical processes. Landfilling is the most common waste management strategy in many countries. Plastic waste landfilling is not favoured today due to quantities of toxic chemicals and their potential for leaching at landfill sites into groundwater which is an environmental and potential health issue [5]. Incineration processing produces toxic gases that pollutes the environment [5]. Mechanical recycling of plastics processes plastics waste into secondary raw material or products, however mechanical recycling itself will lead to downcycling of the plastic waste due to continual recycling. Plastics recycled this way will lose mechanical integrity that renders it unfit for application [5]. Thermo-chemical processes, such as cracking and gasification pose great potential due to its ability to upcycle the plastic waste. Gasification and cracking are similar, as they involve heating to produce short chain hydrocarbons, however gasification requires higher temperatures (800-100 °C) and cracking, thermal or catalytic, does not require such temperatures. The production of liquid products is an advantage of cracking, as gasification mainly produces gaseous products that also has less calorific value due to formation of CO_2 and CO, whereas cracking does not suffer from that problem due to having a small amount of oxygen present. [5, 6]. Cracking is the breaking of complex hydrocarbon chains into simple hydrocarbons. Cracking works in conditions without oxygen to gas and liquid products as well as solid (char). Cracking reaction consists of two main mechanisms, which are primary cracking and secondary cracking. Primary cracking produces hydrocarbon products with short chains in the form of oil, gas, and char, while secondary cracking produces hydrocarbons with shorter and lighter chains than primary cracking [7]. A scheme of cracking reaction pathways can be seen in Fig. 1.

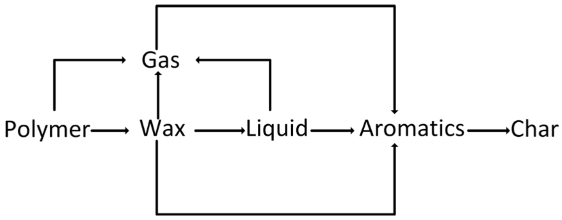


Fig. 1: Illustration of scheme of cracking reaction pathways [8]

Thermal cracking is the breaking of complex hydrocarbon chains into simple hydrocarbons using heat. Thermal cracking generally produces hydrocarbon products that vary between C_3-C_{40}. Thermal cracking is an endothermic process, the operating conditions of thermal cracking is usually in the range of 500-700°C [5, 9]. Catalytic cracking is the breaking of complex hydrocarbon chains into simple hydrocarbons with the aid of a catalyst. Catalytic cracking has an advantage over thermal cracking since it can be carried out at lower operating temperatures. Some studies states that catalytic cracking can already begin to take place at 200-300°C while thermal cracking at temperatures of 500-700°C to get a significant fraction [10]. Catalytic cracking is also more selective in contrast to thermal cracking which gives hydrocarbon products in the range of C_3-C_{40}. Products obtained from the catalytic cracking have better quality, due to the increased levels of cyclic and aromatic components, hence have a better commercial value [5]. Catalytic cracking products are dependent on experiment temperature, catalyst used, catalyst loading (wt%), the type of feed (plastic type), and reaction time [10].

Catalytic cracking using various catalysts has been conducted to determine the effect of Si/Al ratio of the catalyst to the fraction of catalytic cracking products, in that lesser value of Si/Al ratio yielded a greater gaseous product than liquid product due to greater amounts of the end chain cracking occurring [10, 12]. Acidity affects the type of cracking that occurs during primary cracking. Random cracking tends to occur at sites with moderate or weak acidity resulting in liquid products (C_5-C_{12}), while high acid strength promotes end chain cracking resulting in gaseous products (C_1-C_4) [10]. Catalyst such as ZSM-5, SiO_2, and bentonite have been studied and it was found that these catalysts provide good liquid product fractions, however these studies were conducted using variations of a fixed-bed reactor system. ZSM-5 was found to be able to produce a large amount of liquid product (85.0-97.5wt%) at 400-550 °C [13]. Although this process took 3 hours, SiO_2 produced a large amount of liquid product (79.0wt%) at 350 °C [14]. Bentonite was also found to be able to produce a large amount of liquid product (87.5wt%) at 500 °C [15].

Temperature also affects the fraction from the cracking process. At low temperatures, catalytic cracking tends to produce longer chain products, or waxy products, while increasing operating temperatures results in more cracking, i.e. short chain products [9]. However, the increase of operating temperature does not result in more liquid products. Cracking activity is increased at higher temperatures, therefore producing fractions with lower number of hydrocarbon chains.

According to other studies, it was found that if the operating temperature is too high, the gaseous fraction would increase and the liquid fraction would decrease [16]. This result is also supported by other studies, in which it was found that a decrease in the conversion of LDPE to liquid fraction after the temperature was raised, namely from the conversion result of 34.0wt% to 15.0wt% after being raised above 450°C [17].

Reaction time was studied to examine the effect of time spent at a reaction temperature on cracking products. Previous studies on reaction time effect concluded that longer reaction time would increase the activity of secondary cracking, resulting in more short chain products where the gaseous fraction would increase and the liquid fraction would decrease [8]. Studies on cracking at a peak temperature of 450°C discovered a decrease of liquid products, with reaction time of 60 minutes yielded 72.4wt% of liquid products and at reaction time of 90 minutes yielded 69.4wt% of liquid products. The study in the same literature at lower temperatures of 350°C discovered similar results [8, 18].

A study on dissolution of LDPE in cyclohexane and liquid paraffin in thermal cracking of LDPE has determined that cracking using solvent has advantages over cracking without solvent. Cracking of dissolved LDPE was found to occur at much lower temperatures (280-360°C instead of 400-450°C) due to lower viscosities resulting in better mass and heat transfer [11]. Although numerous studies have been done in regards to catalytic cracking of LDPE, studies regarding the effects of dissolution of LDPE during catalytic cracking are scarce, resulting in few studies available.

Previous studies have been conducted in regards to catalytic cracking of LDPE waste. It was determined that catalytic cracking products are dependent on experiment temperature, catalyst used, catalyst loading (wt%), the type of feed (plastic type), and reaction time [10]. The aim of this study was to convert the waste plastics to oil fraction products for use as a hydrocarbon fuel oil and to discover options in cost reduction for catalytic cracking in a batch, pressurised autoclave reactor. Variations in this study include catalyst types (bentonite, SiO_2 and ZSM-5), the effect of acid impregnation of catalyst, catalyst loading (wt%) (1.0wt%; 5.0wt%; 7.0wt%; 9.0wt%; 10.0wt%), the effect of N_2-gas-purging, solvent-to-feed weight-ratios (5:1 and 4:1), temperatures (265°C and 295°C), and reaction time (1-3 hours). The cracking reaction in this study was not carried out at temperatures >300°C due to concerns that higher temperatures would support the production of gas in large quantities and excessive evaporation of the solvent being used (kerosene normal boiling point starts at 150°C) [19]. Variations such as N_2-gas-purging prior to catalytic cracking has not been conducted, to the writer's knowledge, and the potential exclusion of N_2-gas-purging prior to catalytic cracking would lead to further cost reduction, hence increasing its economic feasibility. Although the use of solvents during catalytic cracking has not been widely conducted, the use of solvent in catalytic cracking may lead to further reduction in temperature conditions due to better mass and heat transfer.

Materials and Methodology

Materials. LDPE was procured from collected LDPE waste in Parahyangan Catholic University, Bandung, Indonesia. Then, it was cut to roughly 1×1 cm^2 to fit the reactor. Kerosene was procured from CHEMICALPRO-SMT. Bentonite (purity of 80.0-95.0wt%) was procured from PT. Brataco. ZSM-5 (purity of 96.5-97.0wt%) was procured from Sigma Aldrich. SiO_2 (purity of 99.5wt%) was procured from HiMedia Laboratories Pvt. Ltd. Acid impregnated catalysts were prepared by submerging ZSM-5, Bentonite, and SiO_2 in 2M H_2SO_4 solution, heated for 1 hour with continuous stirring and then stored overnight at room temperature. It was then filtered and washed with distilled water until the pH was neutral and dried at 80°C for 6 hours.

Methodology. The reactor used for this work was a batch pressurised autoclave reactor in Parahyangan Catholic University, Bandung, Indonesia, illustrated in Fig. 2. A rubber seal was inserted into the top of the reactor to prevent leakage of the reactor during the experiments. Kerosene was then poured into the reactor according to the ratio desired. LDPE waste and the desired catalyst was fed to the reactor according to experiment variations. The reactor was then pre-heated to 130°C to melt the LDPE, based on the melting point of LDPE. A magnetic stirrer was also placed inside the autoclave reactor and was turned on at the start of pre-heating to dissolve the LDPE feed. Then, if variations required purging process, purging with N_2-gas was done to remove oxygen to create an oxygen free condition. Pressure inside the reactor was then increased to 20 bar to prevent excess evaporation of the kerosene solvent. Finally, the reactor temperature was increased according to temperature variations for the duration of the experiment variations.

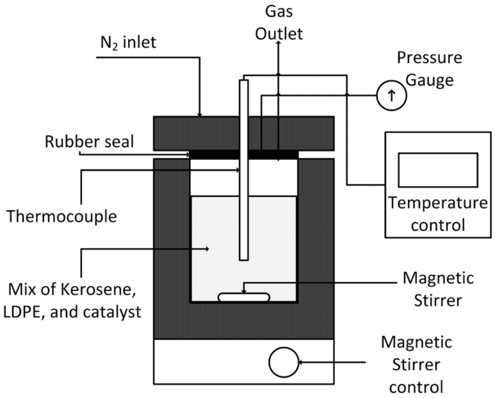


Fig. 2: Illustration of batch pressurised autoclave reactor from Parahyangan Catholic University, Bandung, Indonesia

Analysis

The liquid product was collected and separated from the solid product using a Buchner funnel. The liquid product was then weighed to acquire the weight of the liquid product and liquid fraction was calculated based on Eq. 1. The separated solid product was then weighed to acquire the weight of the solid product and solid fraction was calculated based on Eq. 2. The gaseous product fraction was calculated based on Eq. 3.

$$\%\ \text{Liquid Fraction} = \frac{\text{Mass of Liquid Product}}{\text{Mass of LDPE+Solvent}} \times 100\%. \tag{1}$$

$$\%\ \text{Solid Fraction} = \frac{\text{Mass of Solid Product}}{\text{Mass of LDPE+Solvent}} \times 100\%. \tag{2}$$

$$\%\ \text{Gaseous Fraction} = 100\% - (\%\ \text{Liquid Fraction} + \%\ \text{Solid Fraction}). \tag{3}$$

Further analysis was conducted on the liquid product, such as calorific value analysis, viscosity analysis, density analysis, and GC-MS (Gas Chromatography – Mass Spectrometry) analysis. Analysis of liquid product density was conducted using a pycnometer and density was calculated based on Eq. 4. Analysis of liquid product viscosity was conducted using an Ostwald viscometer and a stopwatch to measure the flow time of the liquid product and viscosity was calculated based on Eq. 5. Calorific value analysis of liquid product was conducted using a bomb calorimeter from Bandung Institute of Technology, Bandung, Indonesia. GC-MS analysis of liquid product was conducted in Bandung Institute of Technology, Bandung, Indonesia.

$$\text{Density of liquid} = \frac{\text{mass of liquid inside pycnometer}}{\text{pycnometer volume}}. \tag{4}$$

$$\text{Viscosity of liquid} = \frac{\text{flow time of liquid} \times \text{density of liquid}}{\text{flow time of water} \times \text{density of water}} \times \text{viscosity of water}. \tag{5}$$

Results and Discussion

Effect of reaction time variations on catalytic cracking of LDPE. Fig. 3 showed that using ZSM-5 (9wt%) at 295°C for two hours in this experiment gave the highest liquid fraction (60.1wt%) compared to one hour (58.4wt%) and a reaction time of three hours (58.3wt%). Fig. 3 also showed that reaction time of 3 hours yielded a slightly larger amount of gas product than the results of 1 hour and 2 hours of reaction time. This is due to increased activity of secondary cracking process on LDPE at longer reaction times, where the secondary cracking increased the production of gas products [7]. These results are also supported by various studies, where similar results were found [8, 18]. Although reaction time of two hours in this experiment gave the highest liquid fraction compared to a reaction time of one hour and a reaction time of three hours, however, the difference in the fraction of liquid products produced at one hour of reaction time when compared to the results of two hours of reaction time and three hours of reaction time was not much different. These results indicated that the one hour of reaction time was sufficient reaction time for LDPE catalytic cracking. One hour of reaction time is also considered to be more economical because the difference of liquid fraction between one hour of reaction time and two hours of reaction time is only 1.7wt%.

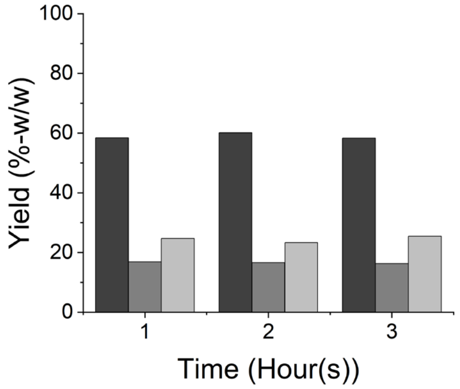
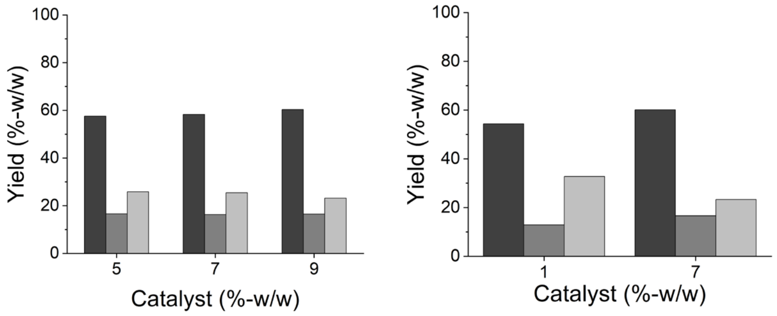


Fig. 3: Product fraction using ZSM-5 (9wt%) at 295°C at various reaction time. (■- Liquid fraction; ▩- Solid fraction; □- Gaseous fraction)

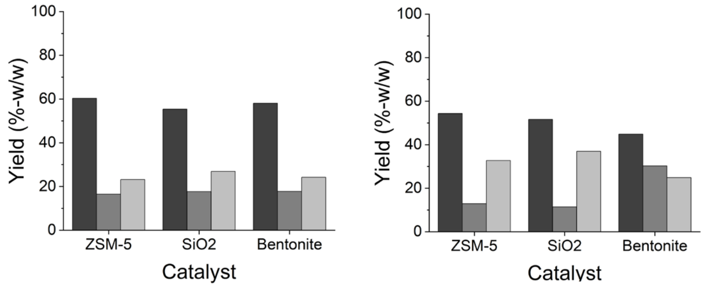
Effect of catalyst loading (wt%) variations on catalytic cracking of LDPE. Fig. 4 showed the product fraction at 295°C using ZSM-5 catalyst at 1.0wt%; 5.0wt%; 7.0wt%; 9.0wt% for 2 hours and 3 hours of reaction time**.** From Fig. 4 (a), the liquid product fraction from catalytic cracking of LDPE conducted for 3 hours using 5.0wt%, 7.0wt%; 9.0wt% were similar. However, it can be seen from Fig. 4 (b) that the liquid product fraction from catalytic cracking of LDPE conducted for 2 hours using 1.0wt% catalyst was 54.4wt%, which was 5.9wt% less than the liquid product fraction when using 7.0wt% catalyst (60.1wt%). This result suggested that at least 5.0wt% may be required to produce more liquid fraction. This is due to the increase in catalyst loading (wt%) that would result in the increase of the liquid products due to increased amounts of active acid sites, where the cracking process occurs [20]. However, when viewed from the difference in liquid products fraction obtained from catalytic cracking conducted for 3 hours using 5.0wt%, 7.0wt%; 9.0wt%, it is around 1-2% and it can be said that there is no significant difference. Thus, the 5wt% catalyst loading was enough to facilitate the LDPE cracking since catalytic action at active sites was within a cycle.



(a) (b)

Fig. 4: Product fraction at 295°C using ZSM-5 at various catalyst loadings (wt%) with reaction times variations as follows: (a) 3 hours; (b) 2 hours. (█- Liquid fraction; ▓- Solid fraction; ░- Gaseous fraction)

Effect of catalyst selection on catalytic cracking of LDPE. Fig. 5 showed that the most liquid product was obtained when ZSM-5 was used. However, the fraction of liquid products among the three types of catalysts can be said to be insignificant, this may be due to other catalyst characteristics aside from number of acid sites in the catalyst.



(a) (b)

Fig. 5: Product fraction at 295°C using various catalyst with reaction times and wt% catalyst variations as follows: (a) 3 hours, 9.0wt%; (b) 2 hours, 1.0wt%. (█- Liquid fraction; ▓- Solid fraction; ░- Gaseous fraction)

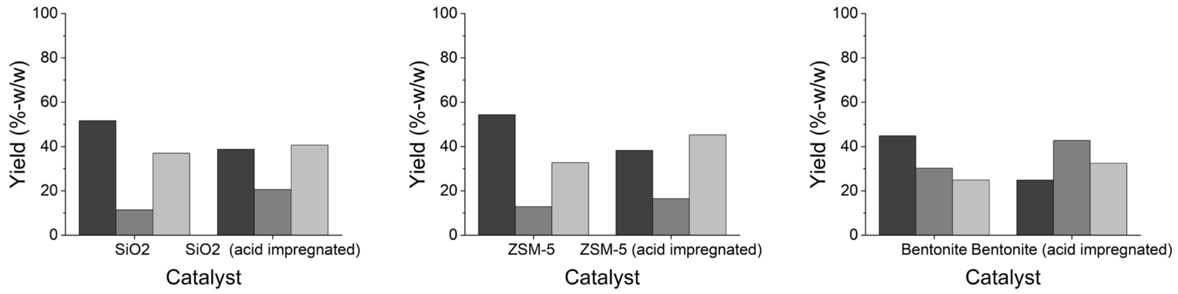
High fraction of liquid products using the ZSM-5 catalyst may be due to ZSM-5 has a high acidity level, ZSM-5 catalyst has Bronsted acid active centers which is the site of cracking as an H+ donor. Bronsted acid is the site of cracking as an H+ donor, which plays an important role in catalytic cracking. The catalyst functions at the initiation step of the cracking process of hydrocarbons, where in the initiation step, Bronsted acid site on the catalyst function to donate H+ ions which forms carbenium ions, then in the propagation step there will be a breaking of the chain bonds (β-scission) which form a shorter carbenium ion and also a shorter alkenes [7, 13].

Table 1. Characteristics of ZSM-5, SiO_2, bentonite catalysts [21, 22, 23].

Catalyst Properties	ZSM-5	SiO_2	Bentonite
Bronsted Acid Sites [μmol/g]	201.0	3.6	10.2
Lewis Acid Sites [μmol/g]	65.0	35.0	59.4
Pore Diameter [nm]	4.2	3.5	7.0

Insignificant difference in the liquid product fraction could be due pore size, which would also affect the activity of cracking [23, 24]. Characteristics of ZSM-5, SiO_2, bentonite catalysts can be seen in Table 1. The pore size gives catalyst feature of shape selectivity, where only small enough molecules can enter the pores. Primary cracking is done in the macroporous surface and secondary cracking is continued in the micropores [20]. The carbon chains of the polymer that can enter the pores are carbon chains that are shorter or smaller than the pores of the catalyst, therefore not all of the active acid centers in the catalyst could be accessed and make these insignificant differences from the results obtained from the three types of catalysts used in this study [21, 22, 23]. From Fig. 5, the most liquid product was obtained when ZSM-5 catalyst was used. However, considering that the fraction of the liquid product was not too different and bentonite was much cheaper, the use of bentonite catalyst from an economic point of view was more desirable.

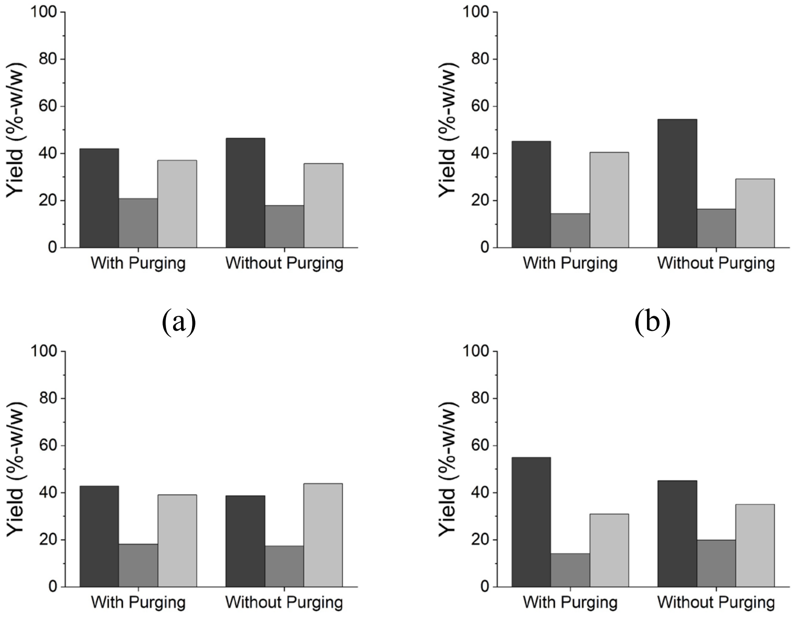
Effect of Acid Impregnation of Catalyst on Catalytic Cracking of LDPE. Fig. 6 showed the liquid yield at 295°C, 2 hours of contact time, and 1.0wt% catalyst at various catalyst acidity variations for SiO_2, bentonite, and ZSM-5. At a temperature of 295°C after acidification of the catalyst, the yield obtained decreased significantly in SiO_2 (from 51.6wt% to 38.8wt%), bentonite (from 44.9wt% to 24.8wt%), and ZSM-5 (from 54.4wt% to 38.2wt%). The decrease in the yield of liquid products could be due to the increase in the number of active acid centers after acid impregnation resulting in more cracking activity that cracked the liquid product into gas product [25]. Although acid impregnation would increase the cracking activity, it can be seen in Fig. 6 that the yield of liquid product decreased and gas products increased on each type of catalyst due to more cracking activity. Literatures from previous experiments support these results, where acid strength would affect the type of cracking that occurs during primary cracking. Random cracking would tend to occur at sites with moderate or weak acidity resulting in more liquid products (C_5-C_{12}), while at sites with high acid strength would lead to end chain cracking which produces gas products (C_1-C_4) [10, 12]. From these results, it can be concluded that the acid impregnated catalyst does not necessarily give better results in obtaining the desired liquid product.



(a) (b) (c)

Fig. 6: Product fraction at 295°C, 2 hours contact time, and 1.0wt% catalyst at various catalyst acidity with catalyst variations as follows: (a) SiO_2; (b) ZSM-5; (c) Bentonite. (█- Liquid fraction; ▓- Solid fraction; ░- Gaseous fraction)

Effect of N_2-gas-purging variations on catalytic cracking of LDPE. Fig. 7 showed that at solvent-to-feed weight-ratios (5:1), 265°C, and without N_2-gas-purging, liquid product fraction was 54.5wt% and at solvent-to-feed weight-ratios (5:1), 295°C, and without N_2-gas-purging liquid product fraction was 54.9wt%. The results showed that N_2-gas-purging resulted in a higher liquid product fraction (wt%) at 295°C. However, without N_2-gas-purging resulted in a higher liquid product fraction (wt%) at 265°C. These results might indicate an interaction between purging and temperature and N_2-gas-purging exclusion could be possible for LDPE catalytic cracking. This would increase the economic competitiveness of the catalytic cracking of LDPE waste.

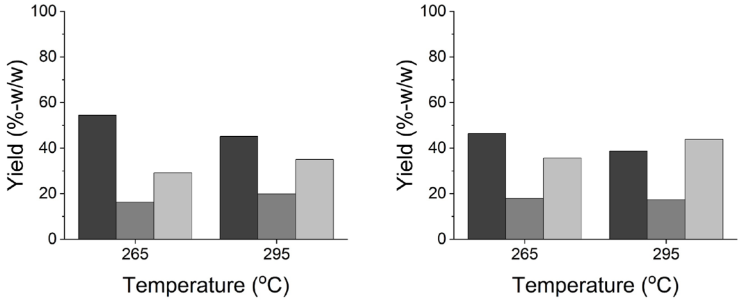


(a) (b)

(c) (d)

Fig. 7: Product fraction using bentonite (10.0wt%) during N_2-gas-purging variations with solvent-to-feed ratios and temperatures as follows: (a) 4:1, 265°C; (b) 5:1, 265°C; (c) 4:1, 295°C; (d) 5:1, 295°C. (■- Liquid fraction; ▩- Solid fraction; □- Gaseous fraction)

Effect of temperature variations on catalytic cracking of LDPE. Fig. 8 showed that without N_2-gas-purging at both solvent-to-feed weight-ratios liquid fraction (wt%) at 265°C was higher compared to 295°C. This study also showed that at 265°C cracking produced higher liquid fraction compared to 295°C, which produced higher gaseous fraction compared to 265°C. These results are in line with previous studies, in which higher temperatures resulted in more cracking, hence more gaseous fraction [5, 9, 17, 18].



(a) (b)

Fig. 8: Product fraction without N_2-gas-purging using bentonite (10.0wt%) for 1 hour at various temperatures with solvent-to-feed weight-ratios as follows: (a) 4:1; (b) 5:1. (■- Liquid fraction; ▩- Solid fraction; □- Gaseous fraction)

It can be concluded that catalytic cracking done without N_2-gas-purging, catalytic cracking at 265°C was better. However, in this study, it was found that the solid product produced from the catalytic cracking was in the form of residue (feedstock that has not yet been cracked) and small amount of char. Other studies that conducted TGA analysis without solvent suggested that conversion at <300°C was low [15, 26].

Effect of solvent-to-feed weight-ratios variations on catalytic cracking of LDPE. Fig. 9 showed the liquid product fraction (wt%) in the variation of the solvent-to-feed weight-ratio (5:1) was greater due to the effect of LDPE dissolution in kerosene solvent. According to other studies, dissolving LDPE in a solvent causes lower viscosity of the feed resulting in better mass and heat transfer, helping the cracking reaction [11, 27, 28]. Dissolving LDPE in light hydrocarbon solvents, in this study, kerosene was used, causes lower viscosity of the feed. This act is usually called visbreaking. Studies suggest that visbreaking helps suppress the production of char products through the hydrogen transfer process [29].

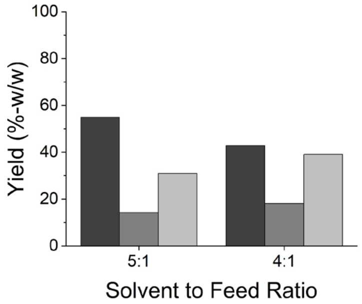


Fig. 9: Product fraction using bentonite (10.0wt%) for 1 hour at various solvent-to-feed weight-ratios at 265°C, and without N$_2$-gas-purging. (■- Liquid fraction; ▨- Solid fraction; ░- Gaseous fraction)

Dissolution of LDPE is not commonly carried out, but studies on the dissolution of other types of plastics has been carried out. The effect of solvent on PS (polystyrene) cracking, in which the results showed that the ideal solvent-to-feed weight-ratio for PS cracking is (1:1) – (7:3) [30]. In this study, variations in solvent-to-feed weight-ratio (4:1) and (5:1), it was found that the variation of (5:1) obtained better results.

In this study, it was found that there was a of loss of kerosene during the catalytic cracking. Further research regarding the use of another solvent with higher boiling point could be done to prevent evaporative losses or addition of a condenser system to prevent excessive losses of the solvent and volatile liquid.

Analysis results for catalytic cracking of LDPE for one hour at 265°C, without purging, using bentonite (10wt%), and solvent-to-feed weight-ratio (5:1). This variation was chosen due to high liquid product fraction at a lower temperature variation, short reaction time and the use cheap bentonite catalyst. The density and the viscosity of the liquid fraction is 800.4 kg/m^3 and 3.9×10^{-2} poise, which are similar to diesel, which are roughly 828.0 kg/m^3 and in the range of 2.0×10^{-2}-5.0×10^{-2} poise. It was also found that the liquid fraction has a calorific value of 46.0 MJ/kg which is similar to diesel, which is in the range of 44.0-47.0 MJ/kg [31]. GC-MS and peak components analysis can be seen in Table 2. which showed that cracking has occurred, shown by the presence of 1,2,3-trimethylbenzene and 1,3-dimethylbenzene, which are aromatic compounds reported in another study on catalytic cracking of LDPE plastic waste [32]. These compounds are uncommon in kerosene, which are mostly n-paraffins (C$_9$-C$_{12}$) and/or iso-paraffins (C$_7$-C$_{12}$) along with cyclo-paraffins, and alkyl derivatives (C$_9$-C$_{12}$). These components in kerosene include cyclohexanes, octanes, nonanes, decanes [19]. However, to better differentiate the compounds found in the solvent and product, GC-MS analysis should also be conducted for the solvent.

Table 2. GC-MS peak components results of liquid product fraction using bentonite catalyst at 265°C for 1 hour, without purging, and solvent-to-feed weight-ratio (5:1). *LDPE cracking products

Peak	R.Time	Area%	Height%	A/H	Name
1	2.5	2.3	3.6	1.7	Cyclohexane, methyl- (CAS) Methylcyclohexane
2	3.0	2.3	2.8	2.2	Cyclohexane, 1,3-dimethyl-, cis-
3	3.2	3.2	4.8	1.7	Octane (CAS) n-Octane
4	3.8	2.2	2.7	2.1	Cyclohexane, 1,1,3-trimethyl- (CAS) 1,1,3 Trimethylcyclohexane
5	4.2	3.7	4.0	2.4	Octane, 2-methyl- (CAS) 2-Methyloctane
6	4.4	2.3	2.7	2.3	Octane, 3-methyl-
7	4.4	3.0	3.8	2.1	*Benzene, 1,3-dimethyl-
8	4.9	7.3	10.3	1.8	Hexane, 2,4-dimethyl-
9	5.7	4.5	4.2	2.8	Nonane, 3-methyl- (CAS) 3-Methylnonane
10	6.3	5.8	2.3	6.4	trans-2-Dodecen-1-ol, trifluoroacetate
11	6.5	4.2	4.1	2.7	Nonane, 2-methyl- (CAS) 2-Methylnonane
12	6.6	2.1	2.1	2.5	Nonane, 3-methyl- (CAS) 3-Methylnonane
13	7.3	6.2	5.2	3.0	*Benzene, 1,2,3-trimethyl- (CAS) 1,2,3-Trimethylbenzene
14	7.4	9.1	10.7	2.2	Dodecane (CAS) n-Dodecane
15	8.0	8.7	8.3	2.7	Decane, 4-methyl-
16	8.2	5.5	4.3	3.3	*Octadecane, 1-chloro- (CAS) 1-Chlorooctadecane
17	8.3	4.5	4.0	2.9	Decane 4-cyclohexyl-, 4-cyclohexyl- (CAS)
18	9.2	4.8	4.9	2.5	Decane, 2-methyl- (CAS) 2-Methyldecane
19	9.4	4.3	4.1	2.7	Decane, 3-methyl-
20	10.3	14.2	11.4	3.2	Tridecane (CAS) n-Tridecane

Concluding Remarks

This study has provided new insight regarding the reduction of process costs, in that N_2-gas-purging exclusion could be possible for LDPE catalytic cracking. This study concluded that the best process condition without using N_2-gas-purging to achieve the highest liquid fraction was 10.0wt%-bentonite in (5:1) solvent-to-feed weight-ratio for 1 hour at 265°C produced 54.5wt% of liquid fraction. Additionally, this study has promoted bentonite as a potentially viable catalyst for LDPE plastic waste catalytic cracking. However, research using higher temperatures (>300°C) may need to be conducted in order to increase conversion of LDPE. From this study, there was a of loss of kerosene during the catalytic cracking, therefore the next step of this study is to fit a condenser system to combat the potential losses volatile liquid products at higher temperatures and evaporative losses of the solvent used. Furthermore, further research regarding the use of another solvent should be done due to evaporation of kerosene and for further cost reduction. A study regarding the deactivation of bentonite needs to be considered in order to optimize the use of bentonite. GC-MS analysis of the solvent used should be done to better differentiate product composition and the solvent composition

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