

Polystyrene Plastic Waste Conversion into Liquid Fuel with Catalytic Cracking Process Using Al_2O_3 as Catalyst

Nurul Kholidah^{1*}, Muhammad Faizal¹, Muhammad Said¹

¹*Chemical Engineering Department, Faculty of Engineering, Sriwijaya University, Palembang 30139, Indonesia*

**Corresponding Author : nurulkholidah92@gmail.com*

ABSTRACT

The increase in energy consumption and an increase in plastic waste generation are two major problems that arise along with economic growth and the increase of population. Styrofoam is one type of polystyrene plastic waste that can be processed into liquid fuels by cracking process. In this study, the cracking process of polystyrene plastic waste into liquid fuel carried by the catalytic cracking process using Al_2O_3 as catalyst. This study aimed to determine the effect of the catalyst weight, length of cracking time and range of temperature in the catalytic cracking process of polystyrene plastic waste into liquid fuel toward the mass and characteristics of liquid fuels produced and to determine the composition of liquid fuels produced. The catalytic cracking process of polystyrene plastic waste with catalyst was done in the fixed bed type reactor by heating the reactor with a heater, where the process took place at temperature of 150°C, 200°C, 250°C and 300°C and the length of the process was varied into 20, 40, and 60 minutes and the catalyst weight was also varied, which were 4%, 6% and 8%, while the styrofoam weight was 250 grams. From the research, the highest mass of liquid fuel derived from polystyrene catalytic cracking process was in the amount of 48.8 grams and liquid yield percentage of 19.5% at temperature of 250°C, cracking time of 60 minutes and weight of 8% catalyst, while the characteristics of liquid fuel that were approaching the characteristics of gasoline was at temperatures of 250°C, cracking time of 60 minutes and weight of 6% catalyst, in which each value of density of 0.763 g/ml, specific gravity of 0.778 and °API gravity of 50.2. While other liquid fuels obtained from the cracking of polystyrene were still within the tolerance range characteristic properties of gasoline. Liquid fuels produced from the catalytic cracking process was analyzed using a GC-MS, in which the analysis results indicated that liquid fuels were included into the gasoline fraction.

Keywords: Plastic Waste, Polystyrene, Al_2O_3 Catalyst, Catalytic Cracking Process

1. INTRODUCTION

Energy is one of the important needs in human life. Energy needs are still dominated by fossil fuels which are not renewable and sooner or later its availability such as petroleum, natural gas, and coal must be exhausted (Arita et al., 2015).

In Indonesia, the energy consumption in various sectors such as transport, industry and electricity for households increased with average growth at steady rate of 5.2% annually, whereas the national energy reserves which is decreasing raised fears of an energy crisis in the future. If there is no found new energy source. Some efforts have been made by the government to overcome the energy crisis, that is by developing alternative fuels derived from renewable energy resources such as hydrogen, nuclear and others. However, research and development of new energy that has been done only focuses on the development of sources of plant materials, mining and nuclear. Though there are many other sources that the potential are quite large as a new energy source. One of

them is waste or trash (Mahendra et al., 2013).

Plastic waste is one of the main problems faced today which can adversely affect humans and the environment because it is non-biodegradable. Based on the assumption of the Indonesia Ministry of Environment, Indonesian population produces 0.8 kg of waste per person everyday, or a total of 189 thousand tons of waste/day. From those amounts, 15% of them is in the form of waste plastic or about 28.4 thousand tons of plastic waste/day.

Plastic waste will have negative impact on the environment because it can not be decomposed quickly and can cause soil contamination. The increase of this plastic waste will become a serious problem if the solution is not sought. Some of waste handling that are popular usually called 3R (Reuse, Reduce, Recycle), but each of the above waste management mentioned has a weakness. Handling of plastic waste can not be done by the method of landfills and open dumping because it would be difficult to unravel. Plastic waste disposal by burning (Incineration) is less effective but it has a risk of the appearance of pollutants from exhaust emissions (CO_2 , CO, NO_x and SO_x) and particulate pollutants (Nindita, 2015).

Another alternative of plastic waste handling is converting plastic waste into fuel oil. This method can be done because the plastic raw materials derived from petroleum derivatives so that it can be returned to hydrocarbons as a basic fuel. This method

Article History:

Received 17 November 2017; revised 10 January 2018; accepted 10 January 2018

<http://doi.org/10.26554/sti.2017.3.1.1-6>

is included in the recycle but the recycling process that is done is not only converting plastic waste directly into the plastic again, but also converting plastic waste into another form of fuel. In this way two important issues can be overcome, which are the May-be pollutant more suitable of large amounts of plastic waste and producing fuel which is one of the plastic raw materials (Surono, 2013). Conversion of plastic waste can be done by the cracking process (Cracking), named from the termination reaction of the C-C bond from a long carbon chain and large molecule weight into short carbon chain with a small molecular weight (Wahyudi et al., 2015).

Polystyrene (PS) is a paraffinic hydrocarbon polymer which is formed by polymerization reaction. Polystyrene is a molecule that has a light molecular weight, formed from aromatic monomer styrene. Polystyrene can not be easily recycled, so that Polystyrene waste must be treated correctly in order not to harm the environment. Polystyrene cracking process is one way to minimize the polystyrene waste. Polystyrene can be found on the CD box, used tires, plastic spoons and forks, plastic cups, or foodbox from styrofoam, and transparent plastic foodbox (Damayanthi and Retno).

Polystyrene cracking process is one way to deal with plastic waste. There are three kinds of cracking process named hydrogen cracking (hydro cracking), high temperatures cracking (hydro cracking) and catalyst cracking (catalytic cracking) (Priyatna et al., 2015).

In this research, the cracking process is done by using a catalyst. The catalytic cracking is a method that often used a catalyst to reduce the high temperature used in the thermal cracking process and to reduce the energy consumption. In the catalytic cracking process, the catalyst used is a solid catalyst. Catalyst used in this research is aluminium oxide (Al_2O_3). Al_2O_3 catalyst is an acid catalyst which can be applied in catalytic cracking reaction. In this catalyst, the aluminium atoms are the main power source of the catalyst. Al_2O_3 has the properties as a thermal insulator and a good electrical insulator and resist to high temperatures so it is often used as catalysts or catalyst supports solids. Al_2O_3 has a violent nature, relatively stable at high temperatures, the structure of the pores are large, easy to shape and has a high melting point. The purpose of this research is to produce liquid fuels from polystyrene waste using Al_2O_3 catalyst by the catalytic cracking process.

The variable used in this research were the variation of catalyst weight, cracking time and temperature. The purpose of this research were to study the influence of the catalyst weight, length of cracking time and cracking temperature toward the mass and characteristics of liquid fuels produced and to study the composition of liquid fuels produced from the catalytic cracking process of polystyrene plastic waste using Al_2O_3 catalyst. As for the benefits of this research was to obtain an alternative fuel derived from waste plastic and in addition can also reduce the negative impact on the environment because the plastic waste will not be decomposed quickly and can lead to pollution of soil.

2. EXPERIMENTAL SECTION

2.1. Time and Place of Research

This research was conducted from August 2016 until December 2016 at the Laboratory of Energy Engineering State Polytechnic of Sriwijaya. Analysis of liquid product composition was conducted in the Laboratory of Organic Chemistry Gadjah Mada University.

2.3. Equipments and Materials

The equipments used in the research were catalytic cracking unit,

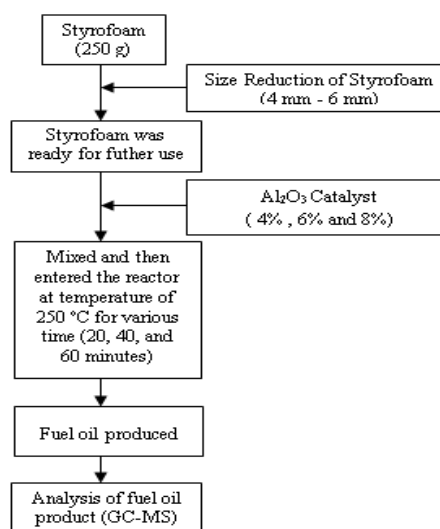


Figure 1. Flow diagram of conversion process polystyrene into fuel oil

Gas Chromatography – Mass Spectrometry (GC-MS), crucible, pycnometer, analytical balance, measurement glass, measurement pipette and beaker glass. While the materials used in the research were polystyrene type of plastics in the form of styrofoam and aluminium oxide. Polystyrene waste plastic were collected from household waste and aluminium oxide catalyst supplied by PT. Bratachem.

The types of polystyrene used were food container and foam packaging. Food particle were cleaned with liquid soap and water inside laboratory manually, then drying naturally using sunlight. At the first stage, the used raw material was reduced the size to 4-6 mm and then weighted according to research variables. Furthermore, 250 g of reduced raw material was mixed with Al_2O_3 catalyst and put in a reactor. Before used, Al_2O_3 had to be activated at 300°C for 3 hours. In this research, the catalyst weight was varied, which were 4%, 6% and 8%. The temperature was 250 °C and the length of the process was varied into 20, 40, and 60 minutes. Catalytic cracking process was done by heating the reactor with a heater. Vapor formed flows from the top of the reactor, condensed and then collected in Erlenmeyer. Operating time was calculated from the first drop of liquid vapor. The fuel oil produced was then collected and sealed for further analysis purpose such as composition characteristics using GC-MS and density test.

3. RESULTS AND DISCUSSION

3.1. Products of Catalytic Cracking Process

The catalytic cracking experiments were carried out in a fixed bed operated at temperature range of 150 °C to 300 °C with Al_2O_3 catalyst. The catalyst weight was varied, which were 4 %, 6 % and 8 % and the length of process would be varied into 20, 40 and 60 minutes. Polystyrene conversion to fuel oil through catalytic cracking process produced solid residue, liquid and gas. The mass of product from polystyrene's catalytic cracking process into fuel can be seen in Table 1.

From the table above, it appeared that the length of cracking time and the weight of the catalyst affected the mass of products produced from the conversion of polystyrene plastic waste into fuel. Time of cracking affected the products because the longer the cracking process took place, the resulting product was increasing (Arita et al., 2015).

Table 1. Mass of Products from Polystyrene's Catalytic Cracking Process

Variable of Experiments			Measured Parameters		
Lenght of Cracking Time (Minute)	Weight Catalyst (%)	Operating Temp. (°C)	Mass of Products		
			Liq (g)	Gas (g)	Solid (g)
20	0	250	20.1	161.6	68.3
40	0	250	22.6	161.7	65.7
60	0	250	24.4	162	63.6
20	4	250	26.8	162.4	60.8
40	4	250	30.5	162.5	57
60	4	250	33.8	163	53.2
20	6	250	35.9	163.6	50.5
40	6	250	39.2	164	46.8
60	6	250	42.5	164.7	42.8
20	8	250	43.7	165.4	40.9
40	8	250	46.6	165.7	37.7
60	8	250	48.8	165.8	35.4

Table 2. Mass of Products from Polystyrene's Catalytic Cracking Process on Different Temperature

Variable of Experiments			Measured Parameters		
Operating Temp. (°C)	Lenght of Cracking Time (Minute)	Weight Catalyst (%)	Mass of Products		
			Liq (g)	Gas (g)	Solid (g)
150	60	6	39.1	160.3	50.6
200	60	6	42.1	161.5	46.4
250	60	6	42.5	164.7	42.8
300	60	6	40.2	169	40.8

From the experimental results, the mass of liquid product produced will be higher as well as the longer cracking time and the more amount of catalyst used. The same phenomenon was happened in the mass of gas product produced. In contrary, the longer the cracking and the higher the amount of catalyst were, the lower the mass of solid residue obtained from the catalytic cracking of polystyrene plastic waste. The highest liquid mass was found in the 60 minutes of cracking time with the amount of catalyst as much as 8%, i.e. 48 g and the lowest value was at the time of cracking process for 20 minutes with the amount of 0% catalyst which was equal to 20.1 g. The highest residual solid mass were at cracking time for 20 minutes with the catalyst amount of 0% that was equal to 68.3 g and the lowest was in cracking time of 60 minutes with the catalyst amount of 8 %, which was 35.4 g. As for the gas product obtained, the highest mass was at cracking time of 60 minutes with the amount of 8 % catalyst that was equal to 165.8 g and the lowest was at the cracking time of 20 minutes with the amount of 0 % catalyst that was equal to 161.6 g. Furthermore, if varried the temperature, we will obtain the same conclusion result as seen in Table 2.

3.2. Characteristics of Liquid Product from Polystyrene's Catalytic Cracking Process

The obtained liquid from catalytic cracking polystyrene plastic waste was characterized without any further processing. The fuel properties like density, specific gravity and °API gravity of the ob-

Table 3. Chemical Properties of Liquid Product from Polystyrene's Catalytic Cracking Process

Variable of Experiments			Analyzed Parameters of Liquid Product		
Lenght of Cracking Time (Minute)	Catalyst Weight (%)	Operating Temp. (°C)	Density (g/mL)	Spgr	°API Gravity
Standards of Gasoline			0.71 - 0.77	0.753	50.46
20	0	250	0.747	0.762	54.1
40	0	250	0.753	0.769	52.6
60	0	250	0.767	0.783	49.2
20	4	250	0.753	0.768	52.7
40	4	250	0.759	0.774	51.3
60	4	250	0.765	0.78	49.8
20	6	250	0.76	0.776	50.8
40	6	250	0.761	0.777	50.6
60	6	250	0.763	0.778	50.2
20	8	250	0.751	0.766	53.2
40	8	250	0.754	0.769	52.4
60	8	250	0.755	0.771	52.1

Table 4. Chemical Properties of Liquid Product from Polystyrene's Catalytic Cracking Process on Different Temperature

Variable of Experiments			Analyzed Parameters of Liquid Products		
Operating Temp. (°C)	Lenght of Cracking Time (Minute)	Catalyst Weight (%)	Density (g/mL)	Spgr	°API Gravity
150	60	6	0.759	0.775	51.1
200	60	6	0.768	0.784	49
250	60	6	0.763	0.779	50.2
300	60	6	0.753	0.768	52.7

tained liquid were measured, as given in Table 3.

Based on table 3, it can be seen that the weight of the catalyst and the length of cracking time from polystyrene plastic waste into liquid fuels affected some quality parameters of the fuel produced. The parameters measured were the density, spgr and °API gravity. From the test results of some of these parameters, density obtained from the research ranged from 0.747–0.767 g/mL, specific gravity ranging between 0.762–0.783, and °API gravity ranging between 49.2–54.1. The longer the time of cracking was, then the value of density and specific gravity of liquid fuels produced were increasing also. But on the contrary, the longer the cracking time, then the value of °API gravity was getting low.

The purpose of this parameter testing was to determine the best variety to get fuel with good quality in accordance with the standard parameters of gasoline. From the results of parameters analysis, the derived fuel that met the standard parameters of gasoline was contained in the variation of 6 % catalyst with cracking time of 60 minutes, which each value of the parameters was 0.763 g/mL of density, specific gravity of 0.778, and °API gravity of 50.2.

As for the relation between the length of cracking time and the weight of catalyst toward the yield percentage of liquid at temperature of 250 °C with the Al₂O₃ catalyst can be seen in Figure 2 below.

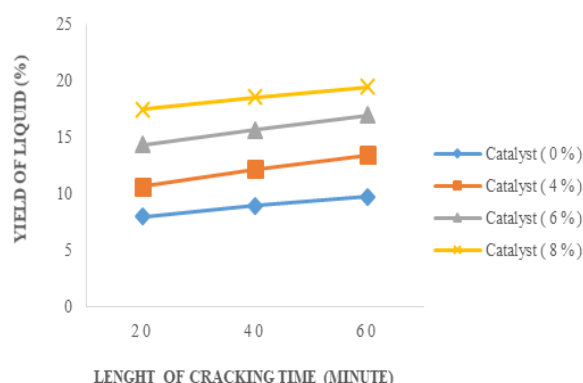


Figure 2. Effect of cracking time and percentage of catalyst toward percentage of liquid yield

According to reference Salamah and Maryudi (2016), the increasing of liquid products were affected by the length of cracking time, cracking temperature, the optimum condensation process and catalyst because of these factors that influence the process of decomposition of hydrocarbons.

Based on Figure 2, it can be seen the effect of the length of cracking time and the catalyst weight toward the yield percentage of liquid fuels produced. It was found that the yield percentage of liquid fuel products continued to increase along with the length of cracking time and the addition of the catalyst weight. Based on the theory, the longer of reaction time, the more product will be formed, this was because the reactants would be cracked completely in line with the increase of time (Miskah et al., 2016). As well as with the addition of a catalyst, in a variation ratio of catalyst/plastic, the liquid yield obtained increased with the increasing ratio of catalyst/plastic. This is because the higher amount of the catalyst added would increase the reaction rate of product formation by lowering the activation energy (Wahyudi et al., 2015).

Reference Damayanthi and Retno, did a research using Polystyrene and Zeolit and ZSM-5 as catalyst with the weight of 0.5 g until 1.5 g at temperature variation of 500 until 600°C concluded that most liquid obtained from the catalytic cracking was 17.7 ml, derived from scrap tires as much as 50 gs with HY and ZSM-5 catalyst as much as 1.5 g at a temperature of 600°C.

In this research, the highest percentage of liquid yield was shown in the operating time of 60 minutes which was equal to 9.8 %, 13.5 %, 17.0 % and 19.5 % and the lowest percentage of liquid yield was shown in the operating time of 20 minutes, which were 8.0 %, 10.7%, 14.4 % and 17.5 % with the addition of catalyst respectively of 0 %, 4 %, 6 % and 8 %. While at cracking time for 40 minutes with the addition of the catalyst as much as 0 %, 4 %, 6 % and 8 % the product obtained were 9.0 %, 12.2 %, 15.7 % and 18.6 %.

3.3. Effect of Cracking Time and Percentage of Catalyst toward Conversion Percentage of Products

The relationship between the length of cracking time and the weight of catalyst toward the conversion percentage of products at temperature of 250 °C with the Al_2O_3 catalyst can be seen in Figure 3 below .

Operating time is very important on the product to be pro-

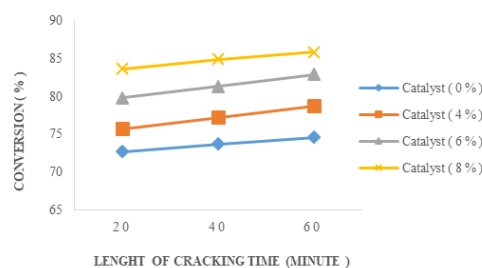


Figure 3. Effect of cracking time and percentage of catalyst toward conversion percentage of product

duced because the longer time of the cracking process took place, then the resulting product (oil, tar and gases) would also increase (Hamid et al.).

As well as the catalyst, reference Syamsiro (2015) stated that the presence of the catalyst had an important role in the cracking process because it can reduce energy needs compared with those without a catalyst and resulted in the formation of hydrocarbon branches more. The catalyst can also reduce the reaction time of initiation and improve the quantity and quality of the output product. While according to reference Sya'diyah and Juliastuti (2015), The higher amount of catalyst will degrade long-chain hydrocarbon into a simpler compounds through the formation of free radicals. Each free radicals generated will induce other compounds to form a new radical with a number of smaller atoms.

Figure 3, showed the effect of cracking time and the addition of the catalyst to conversion percentage of products resulting from the process of polystyrene plastic waste's catalytic cracking into fuel. In this experiment, the product resulted from the process of polystyrene plastic waste conversion were liquid, solid and gas. The conversion percentage of the product was the total yield of the product (liquid, gas and solid) obtained from the cracking of polystyrene plastic waste. The longer the cracking time and more the amount of catalyst were, the liquid yield and gas yield were likely to increase, as opposed to a solid yield. This was because the longer the cracking time was, the reactants would be cracked perfectly, as well as also with the addition of the catalyst, the more the amount of catalyst would increase the reaction rate of product formation.

From the figure above, it appeared that the longer the cracking time was, the higher the percentage conversion of the resulting product. As well as the addition of a catalyst in the process, the higher the amount of catalyst, the higher the percentage of conversion was. The conversion percentage of highs and lows were shown in the operating time of 60 minutes which was equal to 74.6 %, 78.7 %, 82.9 % and 85.8 %, and 20 minutes for 72.7 %, 75.7 %, 79.8 % and 83.6 % with the addition of the catalyst respectively of 0 %, 4 %, 6 % and 8 %. While at cracking time for 40 minutes with the addition of the catalyst as much as 0 %, 4 %, 6 % and 8 % was obtained as much as 73.7 %, 77.2 %, 81.3 % and 84.9 %.

3.4. Effect of Temperature toward Percentage of Liquid Yield

The relationship between temperature toward the yield percentage of liquid produced from the catalytic cracking of polystyrene plastic waste with cracking time of 60 minutes and the amount of catalyst as much as 6 % can be seen in Figure 4.

Based on Figure 4, it can be seen that the higher the tem-

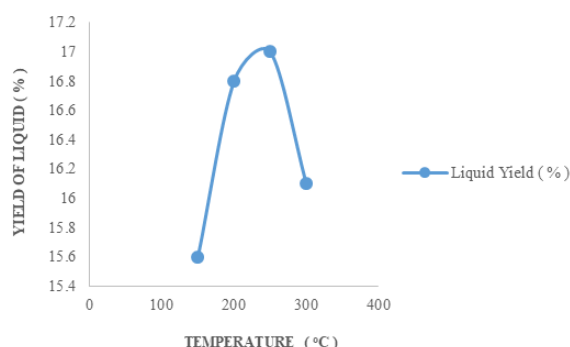


Figure 4. Effect of Temperature toward Percentage of Liquid Yield

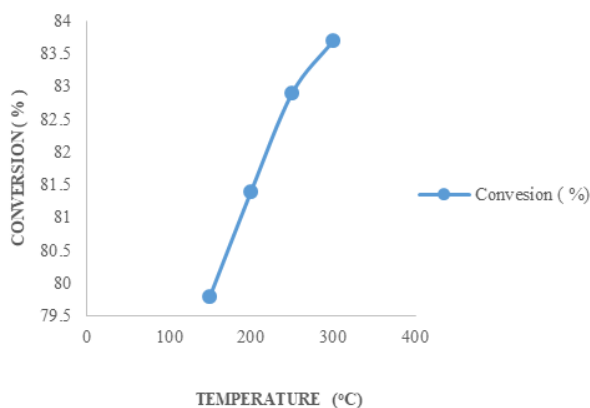


Figure 5. Effect of temperature toward conversion percentage of product

perature was, the yield percentage of liquid produced from the cracking process was increased also. The higher the temperature was, the yield of liquid produced from the cracking process was also getting higher. This was happened because the higher temperature was, the carbon chain will be more easily cracked than the low temperature (Priyatna et al., 2015).

Reference Wardana et al. (2016) stated that high temperatures also resulted in the decline of liquid's quantity and the increasing of gaseous product. It was caused by secondary cracking process that broke down long-chain organic compounds and hydrocarbons into shorter chains that can not be condensed.

The graph above showed the highest percentage of liquid yield was obtained at a temperature of 250 °C which was equal to 17.0 %, while the lowest percentage of liquid yield was at temperature of 150 °C that was equal to 15.6 %. However, at temperature of 300 °C the yield percentage yield of liquid decreased that was equal 16.1 %, this was because at higher temperature, the yield of the gas produced more than the yield of liquid.

3.5. Effect of Temperature toward Conversion Percentage of Products

The relationship between the effect of temperature on the percentage of products conversion from the catalytic cracking of polystyrene plastic waste with a cracking time of 60 minutes and the amount of catalyst as much as 6 % can be seen in Figure 5.

From the graph above it can be seen that temperature affected

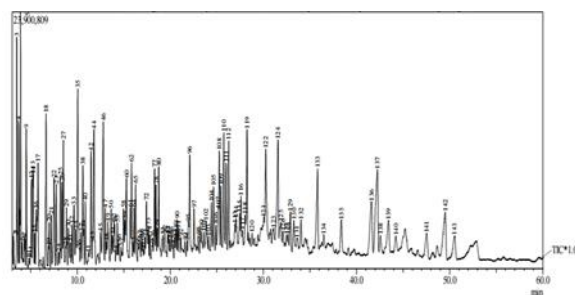


Figure 6. GC-MS Analysis (temperature of 250 °C, 6 % Al_2O_3 catalyst and cracking time of 60 minute)

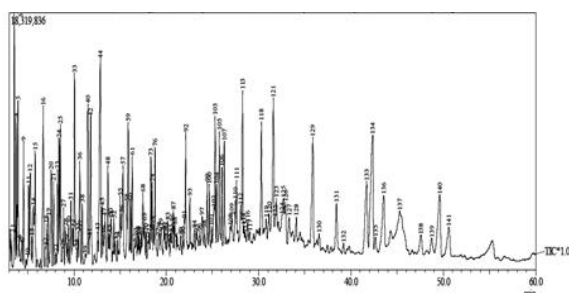


Figure 7. GC-MS Analysis (temperature of 150 °C, 6 % Al_2O_3 catalyst and cracking time of 60 minute)

the product resulting from the process of catalytic cracking from polystyrene plastic waste. The higher the temperature was, the percentage of conversion products was increasing also. According to Nazif et al. (2016), the increasing of the cracking temperature made the conversion also increased, because produced more smaller molecules. As for the effect of temperature, reference Houshmand et al. (2013), who did an experiment using Polystyrene with a novel catalyst stated that the higher the temperature of process was, the conversion of product were higher also.

At temperature of 300 °C, the conversion percentage of the product reached the value of 83.7 %, which was the highest percentage conversion products compared with a conversion percentage at other temperature variations. For an operating temperature of 150 °C, 200 °C and 250 °C respectively conversion percentage was 79.8 %, 81.4 % and 82.9 %.

3.6. Gas Chromatography-Mass Spectrometry (GC-MS) Analysis

Analysis using GC-MS instrument was conducted to determine the number and content of hydrocarbon elements contained in the liquid product produced from the process of polystyrene plastic waste's catalytic cracking.

The results of GC-MS analysis for liquid product at temperature of 150 °C and 250 °C, cracking time of 60 minute and catalyst weight of 6 %, it can be seen in figure 6 and figure 7.

The liquid products have been classified into three groups i.e. the gasoline fraction ($\text{C}_5\text{-C}_{12}$), diesel fuel fraction ($\text{C}_{13}\text{-C}_{20}$) and heavy oil ($> \text{C}_{20}$). Based on the figure 6 and figure 7, the composition of the liquid fuel produced consisting of alkenes (olefins), alkanes (paraffin), aromatic hydrocarbons and other compounds. From the analysis using a GC-MS, it can be seen that the liquid product produced containing gasoline fraction ($\text{C}_5\text{-C}_{12}$) was higher compared with other factions.

4. CONCLUSION

Polystyrene conversion to fuel oil by catalytic cracking process using Al_2O_3 catalyst experiment was intended to find the optimum condition. There are some factors to be considered to achieve that goal; among them are the use of catalyst, the length of cracking time and optimum operating condition. From the experiment conducted, it can be concluded that:

1. The variation of catalyst weight, the length of cracking time and temperature of catalytic cracking process influence the percentage yield of product.
2. The characteristics of liquid fuel were approaching the characteristics of gasoline that is at temperatures of 250 °C, cracking time of 60 minutes and catalyst weight of 6 %, in which each value of density of 0.763 g/mL, specific gravity of 0.778 and °API gravity of 50.2.
3. The optimum conditions catalytic cracking process of polystyrene plastic waste with Al_2O_3 catalyst is at temperature of 250 °C with catalyst amount of 8 %, which produced 19.5 % yield of liquid product.

REFERENCES

- Arita, Susila., Assalami, Abrar., Naibaho, Dina Irawaty., 2015. Proses Pembuatan Bahan Bakar Cair dengan Memanfaatkan Limbah Ban Bekas Menggunakan Katalis Zeolit. Jurnal Teknik Kimia No. 2, Vol. 21.
- Nugraha, Mahendra Fajri., Wahyudi, Arifuddin., Gunardi, Ignatius., 2013. Pembuatan *Fuel* Dari *Liquid* Hasil Pirolisis Plastik Polipropilen Melalui Proses Reforming Dengan Katalis $\text{NiO}/\text{T-Al}_2\text{O}_3$. Institute Teknologi Sepuluh Nopember (ITS).
- Nindita, Velma., 2015. Studi Berbagai Metode Pembuatan BBM dari Sampah Plastik Jenis LDPE Dan PVC Dengan Metode Thermal & Catalytic Cracking (*Ni-Cr/Zeolit*). TEKNIS, Volume 10, Nomor 3 : 137 –144.
- Surono, Untoro Budi., 2013. Berbagai Metode Konversi Sampah Plastik Menjadi Bahan Bakar Minyak. Jurnal Teknik Vol.3 No.1, ISSN 2088 – 3676.
- Wahyudi, Ekky., Zultinir., Edy Saputra., 2015. Pengolahan Sampah Plastik Polypropylene (PP) Menjadi Bahan Bakar Minyak dengan Metode Perengkahan Katalitik Menggunakan Katalis Zeolit X. JOM FTEKNIK Volume 2, No 2.
- Damayanthi, Reska., Martini, Retno., Proses Pembuatan Bahan Bakar Cair dengan Memanfaatkan Limbah Ban Bekas Menggunakan Katalis Zeolit dan ZSM-5. Jurusan Teknik Kimia, Fakultas Teknik.
- Priyatna, Aldi Okta., Zultinir., Saputra, Eddy., 2015. Perengkahan Katalitik Limbah Plastik Jenis *Polypropylene (PP)* Menjadi Bahan Bakar Minyak Menggunakan Katalis Zeolit A. JOM FTEKNIK Volume 2 No 2.
- Salamah, Siti., Maryudi., 2016. Pirolisis Sampah Sterofoam dengan Katalis Ni/Silika. Simposium Nasional Teknologi Terapan (SNTT) 4, ISSN : 2339-028X. Prog Studi Teknik Kimia , Fakultas Teknik Industri , Universitas Ahmad Dahlan.
- Miskah, Siti., Gumay, Niken Puteri., Yuliani, Ovia., 2016. Pengolahan Limbah Plastik Menjadi Bahan Bakar Cair dengan Proses Catalytic Cracking. Fakultas Teknik. Universitas Sriwijaya.
- Hamid, Rusdianto., Djide, Muhammad Natsir., Ibrahim, Roslinda., Penanganan Limbah Plastik dengan Teknologi Pirolisis dan Biodegradasi dengan Bakteri *Pseudomonas SP*. Universitas Hasanuddin.
- Syamsiro, Mochamad., 2015. Kajian Pengaruh Penggunaan Katalis terhadap Kualitas Produk Minyak Hasil Pirolisis Sampah Plastik. Jurnal Teknik Vol. 5 No. 1, ISSN 2088 – 3676.
- Sya'diyah, Khalimatus., Juliastuti, Sri Rachmania., 2015. Pengaruh Jumlah Katalis Zeolit Alam pada Produk Proses Pirolisis Limbah Plastik Polipropilen (PP). Jurnal Bahan Alam Terbarukan.
- Wardana, Novan Yuda., Caroko, Novi., Thoharudin., 2016. Pirolisis Lambat Campuran Cangkang Sawit dan Plastik dengan Katalis Zeolit Alam. Teknoin Vol. 22 No 5 : 361-366
- Nazif, Rio., Wicaksono., Erlangga., dahlia, Halimatud., 2016. Pengaruh Suhu Pirolisis dan Jumlah Katalis Karbon Aktif terhadap Yield dan Kualitas Bahan Bakar Cair dari Limbah Plastik Jenis Polipropilena. Jurnal Teknik Kimia USU, Vol. 5, No. 3.
- Houshmand D, B. Roozbehani and A. Badakhshan. 2013. Thermal and Catalytic Degradation of Polystyrene with a Novel Catalyst. Int. J Sci. Emerging Tech Vol-5.