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Processing Mixture of Polypropylene (PP) Plastic Waste and Palm Fiber Waste into Alternative Fuels

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Abstract

The increasing accumulation of plastic and industrial biomass wastes, as well as the declining reserves of petroleum as an energy source, have become significant topics of discussion. Therefore, this research aims to determine alternative energy sources in the form of fuel derived from cracking a mixture of Polypropylene (PP) plastic waste and palm fiber waste (PFW) waste. It also aims to determine the quantity and quality like calorific value analysis and GC-MS (Gas Chromatography - Mass Spectrometry) analysis of the derived products. The cracking process with a catalyst to feed ratio of 1:10 and a time of 40 minutes led to the highest % yield of oil liquid product (OLP) product of 48.08% with the variation condition of PP to PFW ratio of 1.5:1 at a temperature of 500°C. The GC-MS analysis results showed that the area % of the OLP product contains fuels, such as gasoline (32.97%), kerosene (5.36%), and diesel (2.24%). It will be able to be an alternative fuels.

Keywords: Cracking, Polypropylene, plastic waste, palm fiber, alternative energy

Abstrak (Indonesian)

Meningkatnya akumulasi limbah, baik itu sampah plastik maupun limbah biomassa hasil industri, serta menurunnya cadangan minyak bumi sebagai sumber enegi, menjadi topik masalah yang cukup signifikan untuk dibahas dan dicarikan solusinya. Penelitian dilakukan dengan tujuan mencari sumber energi alternatif berupa bahan bakar yang berasal dari perengkahan campuran sampah plastik jenis PP (*Polypropylene*) dan limbah biomassa serabut kelapa sawit (PFW), serta mengetahui kuantitas dan kualitas seperti analisis nilai kalor dan analisis GC-MS (Gas Chromatography - Mass Spectrometry) dari produk yang dihasilkan. Perengkahan yang dilakukan dengan perbandingan katalis dan umpan 1:10 dan waktu 40 menit, menghasilkan %konversi produk CHP (Cairan Hasil Perengkahan) tertinggi sebesar 48,08% dengan kondisi variasi rasio PP:PFW adalah 1,5:1 dan suhu 500°C. Hasil analisa GC-MS menunjukkan % area produk CHP tersebut mengandung bahan bakar seperti bensin (32,97%), minyak tanah (5,36%) dan solar (2,24%). Ini akan bisa menjadi bahan bakar alternatif.

Kata Kunci: Perengkahan, Polypropylene, sampah plastik, serabut kelapa sawit, energi alternatif

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INTRODUCTION

The increasing energy demand is inversely proportional to its reserves in the form of oil, which has a downward trend. Oil demand is predicted to increase to 1.93 million BOPD by 2025 [1]. Indonesia's oil reserves decreased from 8.21 billion barrels in 2008 to 7.5 billion barrels in 2018 [2]. So that alternative technologies such as cracking are needed. Cracking is a method used to generate energy by breaking down polymer chains into compounds with lower molecular weights [3]. Abdel and Ali [4] investigated the catalytic cracking of a mixture of plastic bag and plastic bottle waste. The GC-MS analysis result of the cracking product showed that the hydrocarbon liquid was similar to gasoline with a percentage of 83.5%. Juwono [5] investigated on the catalytic conversion of PP plastic waste with a silica-alumina ceramic catalyst and found that hydrocarbon fuels (C_8-C_{12}) was synthesized by 11.08 grams.

Preliminary research showed that waste, especially plastic waste, has been widely used as the basic material for the cracking process. Waste is used due to its significant amount in the world, which increase with a rise in the human population. According to statistical data collected on June 2021, Indonesia has about 272.2 million people. Meanwhile, the 2020 census indicates that the population increased by 32.56 million from 2010. Based on data from the Central Bureau of Population Statistics, Jambi Province, Jambi City also experienced an increase in population from 2016–2019, resulting in 353974; 591340; 597043, and 604923 inhabitants. Subsequently, the total volume of the city's waste during this period was 166118.7; 168354.6; 169,978.2; and 169977.9 tons [6].

Plastic waste adversely affects the environment [7]. Based on data from the Indonesian Plastic Industry Association (INAPLAS) and the Central Statistics Agency (BPS), Indonesia is the second-largest plastic waste contributor globally, with a total of 64 million tons/year. Plastics take billions of years to degrade naturally [8]. In 2016, it contributed to 12.3% of the total waste produced in Jambi [6].

One of the most common types of plastic waste is Polypropylene (PP), with excellent chemical resistance. Maddah [8] stated that PP waste can be processed through many conversion methods, such as injection molding and extrusion. This research was conducted by processing PP plastic waste commonly used in the manufacture of household appliances, furniture, auto parts, food packaging products, textiles, and stationery [9].

Industrial-related waste, such as biomass, also significantly increases in number. Indonesia, specifically Jambi Province, is very famous for its oil palm plantation industry (*Elaeis guineensis Jacq.*), which plays an important role in the country's economy [10]. A 2017 data from BPS reported an increase in the area of oil palm land by 10.47 million hectares in 2013 to 12.3 million hectares in 2017. Furthermore, its CPO production increased from 17.77 million tons in 2013 to 34.47 million tons in 2017. The province also experienced an increase from 689966 Ha in 2015 to 1079334 Ha in 2018. Meanwhile, its CPO production increased from 1,619,896 tons in 2015 to 1813870 in 2018 [12]. This increase significantly impacted the amount of waste generated.

Palm oil waste is obtained from plantation and milling activities. It generally contains high organic matter that adversely leads to environmental pollution. The main biomass waste sources from processing fresh fruit bunches (FFB) in palm oil mills include empty fruit bunches, shells, and fiber [13]. The main components of oil palm fiber (PFW) are cellulose (59.6%), lignin (28.5%), crude protein (3.6%), fat (1.9%), ash (5.6%), and impurities (8 %) [14]. In addition to processing PP plastic waste, this research also added palm oil fiber biomass as a mixture in the catalytic cracking process. This is because PFW as cellulose is dominated by carbon [15]. Carbon can be the main ingredient for making fuel.

Preliminary research analyzed the mixing of biomass and plastic waste in the catalytic cracking process Zheng et al., [16]. This research showed cracking a mixture of LDPE plastic waste and pine biomass. The results showed that the two materials' mixture helps break down the C bond. As a non-biodegradable material, plastic melts first and covers the biomass, which breaks its polymer bonds [16].

This research was conducted to determine alternative energy sources by cracking a mixture of PP plastic and PFW waste. It also aims to determine the quantity and quality like calorific value analysis and GC-MS (Gas Chromatography - Mass Spectrometry) analysis of the derived products. This will help to reduce plastic and biomass waste, found in large numbers in the environment.

MATERIALS AND METHODS

Materials

The type of PP plastic waste used was obtained from the Kota Baru Jambi Waste Bank, chopped to a size of 2x2 mm, and cleaned. Meanwhile, PFW was obtained from local palm oil mild in Jambi, chopped to a size of 2x1 mm and cleaned in an oven at 60 ˚C for 2 hours. The used catalyst of FCC (Fluid Catalytic Cracking) was obtained from PT Pertamina Refinery in Palembang and then reactivated by calcination at a temperature of 450 ˚C for 10 minutes. Nitrogen gas was supplied from local distributor.

Catalytic Cracking of Mixture of Polypropylene (PP) Plastic Waste and Palm Fiber

The Steepest Ascent Method was used to optimize the cracking process, namely to determine the operating conditions that maximize the yield of the PP and palm fiber cracking process. The steepest ascent method was used to determine the effect of weight ratios of P:PFW (0.5:1, 1:1, and 1.5:1) and temperature (400 ˚C, 450 ˚C, and 500 ˚C) in the form of OLP quantity. The research Design and matrix for cracking mixture of PP and PFW waste can be seen in **Table 1** and **Table 2**, respectively.

Table 1. Research Design for Cracking Mixture of PP and PFW Waste

Condition	X_1	X_2
1	-1	-1
2	-1	1
3	1	-1
4	1	1
5	0	0
6	0	0
7	0	0

Table 2. Research Matrix on Cracking Mixed PP and PFW Waste

Condition	Ratio of PP:PFW (X_1)	Temperature Variation (X_2) (˚C)
1	0.5:1	400
2	0.5:1	500
3	1.5:1	400
4	1.5:1	500
5	1:1	450
6	1:1	450
7	1:1	450

The cracking process was conducted for 10 minutes with a catalyst to feed ratio of 1:10. Cracking was performed by mixing PP plastic waste, PFW, and a catalyst. Cracking Result Liquid (OLP) was calculated to determine its conversion or quantity according to Sangpacth et al. [17] formula as follows:

$$\text{OLP (\%)} = \frac{\text{CHP product weight}}{\text{Initial weight of raw natural}} \times 100\%$$

The quality of OLP was analyzed using the calorific value test at Jambi University and GC-MS Organic Chemistry Lab UGM. Meanwhile, the characterization of spent FCC catalysts was tested to determine the XRD and SEM at the ITB Laboratory.

RESULTS AND DISCUSSION

OLP

Cracking is the process of breaking polymer chains into their main monomers [18]. As shown in **Figure 1**, OLP is the main product of this process. Furthermore, the by-products in coke and gas were also obtained.

The cracking process showed that the overall physical form of OLP was relatively the same. It has a brown color and emits a pungent odor typical of fuel. Furthermore, OLP has an impure hydrocarbon compound that contains organic compounds and other impurities.

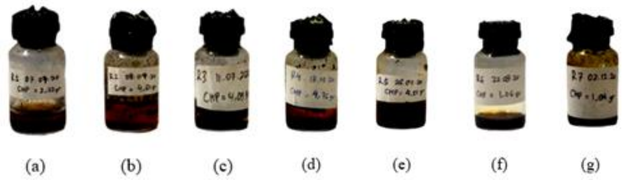

Figure 1. OLP from a mixture of PP plastic and PFW

OLP Quantity

Table 3 shows that the fourth condition using the OLP conversion with a PP to PFW ratio of 1.5:1 at a temperature of 500˚C produces the highest % value. The result was then analyzed statistically using the MATLAB application to determine the effect of variations in the PP to PFW ratio (0.5:1, 1:1, and 1.5: 1) and temperature variations (400°C, 450°C, and 500°C) on % OLP.

Table 3. Data on OLP from a mixture of PP plastic and PFW waste

	PP:SK Ratio (X_1)	Temp (X_2) ˚C	Catalyst/ Feed ratio	Time (min)	OLP (g)	% OLP
1	0.5:1	400	1:10	40	2.22	22.42
2	0.5:1	500	1:10	40	4.51	45.56
3	1.5:1	400	1:10	40	4.09	41.31
4	**1.5:1**	**500**	**1:10**	**40**	**4.76**	**48.08**
5	1:1	450	1:10	40	4.51	45.56
6	1:1	450	1:10	40	1.06	10.71
7	1:1	450	1:10	40	1.94	19.60

Table 4 shows that the F-count is smaller than F-table. Therefore, it can be concluded that the process of cracking a mixture of PP plastic waste and PFW is not optimal using the model. This is also in accordance with **Figure 2**, which shows that the results did not reach the maximum optimum condition. The matrix resulted from research design using the Steepest Ascent Method. This method optimizes the cracking process to determine the operating conditions that maximize the results

Table 4. Results of Statistical Analysis on OLP from a mixture of PP plastic and PFW waste

	R (b1, b2Ib0)	Error	SDM	GM	total
DB	2	4	2	2	6
JK	338.25	1061.3	405.52	655.83	1399.6
KT	169.12	265.34	202.76	327.91	0
F-count	0.6374	0	0.61833	0	0
F-table	0	19	0	0	0

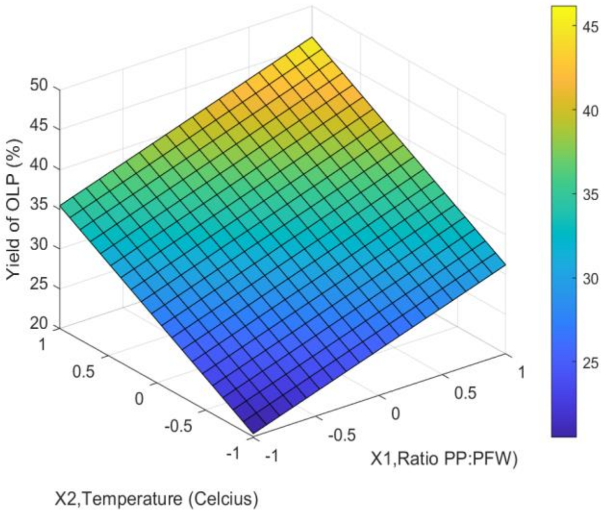

Figure 2. Response graph of the influence of X_1 and X_2 variables on % OLP results

OLP Quality

OLP with the highest quantity is then tested to determine the quality. Analysis of OLP quality is carried out by measuring several parameters, including calorific value analysis and GC-MS (Gas Chromatography - Mass Spectrometry) analysis [19]. Calorific value is the amount of heat energy released by the fuel to oxidize the existing chemical elements [20]. The 4th cracking condition have a calorific value of 21138 MJ/Kg. The higher the calorific value of a fuel, the more efficient the energy produced with less mass [21].

GC-MS analysis was carried out to determine the chemical components contained in the product, which is shown in the % area. The % area is determined based on the compounds identified from the GC-MS results [20]. GC-MS results showed 43 compounds contained in the tested OLP. The compound with the largest % area of 23.21% is benzenesulfonic acid, 4-hydroxy- with the molecular formula $C_6H_6O_4S$ and a weight of 174 (gr/mol). The compound is a compound with a length of C6 hydrocarbons. After calculating the range of C atoms belonging to the compound in the tested OLP, is the similarities with an area of 32.97% are determined. Gasoline is a short-chain hydrocarbon between C_4-C_{10}, commonly used for motor vehicle fuel and in the form of a clear, slightly yellowish liquid. It is mostly composed of aliphatic hydrocarbons enriched with iso-octane or benzene to increase the octane rating [22]. In addition to having similarities with gasoline, the GC-MS results also showed that the tested OLP has similarities with 5.36% kerosene and 2.24% diesel.

Catalyst Characterization

This analysis process aims to determine the lattice parameters, crystal size, crystalline phase, and morphological surface of catalyst.

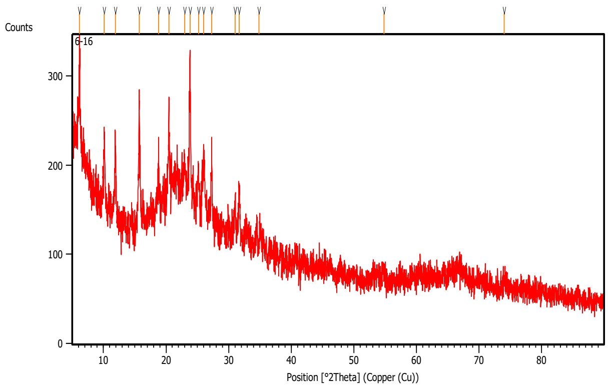

Figure 3. XRD diffraction pattern of Spent FCC catalyst after reactivation

Figure 3 shows that specific peaks appear in the crystal structure of the spent FCC catalyst, which has a crystalline phase indicated by the appearance of strong and sharp peaks. Furthermore, the crystal phase of the FCC catalyst is characterized by sharp diffractogram peaks in the 2θ region between 18° and 25°. Its structure in the 2θ position ranges from 6-30. Meanwhile, all peaks of the Spent FCC catalyst have high intensity at 2θ = 6.2˚, 10.12˚, 20.4˚, 23.8˚, 27.2˚, and 31˚.

The Scanning Electron Microscope (SEM) analysis was used to determine the morphology of the Spent FCC catalyst. Figure 4 shows the structure of the spent FCC catalyst in the form of lumps. Therefore, it can be concluded that the crystals formed are not crystalline and less uniform. Figure 4 also shows that the crystals have an amorphous shape with aggregates, and the morphology consists of pores of irregular size.

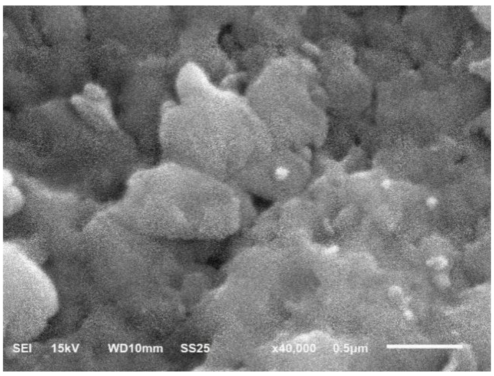

Figure 4. FCC Spent Catalyst SEM with 40,000× magnification

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CONCLUSION

The following conclusions were obtained from the cracking mixture of PP plastic and PFW waste:

1. The product quantity of OLP from the mixture of PP plastic and PFW waste using Spent FCC catalyst is quite high, with a conversion of 48.08%.
2. The highest quality of OLP products is the mixture of PP plastic and PFW waste using a Spent FCC catalyst with a calorific value of 21.138 MJ/Kg. Meanwhile, the GC-MS analysis result shows that the product area contains fuels such as gasoline (32. 97%), kerosene (5.36%), and diesel (2.24%).

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