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The effectiveness of plastic waste pyrolysis reactor with a zeolite catalyst as an appropriate technology in producing kerosene

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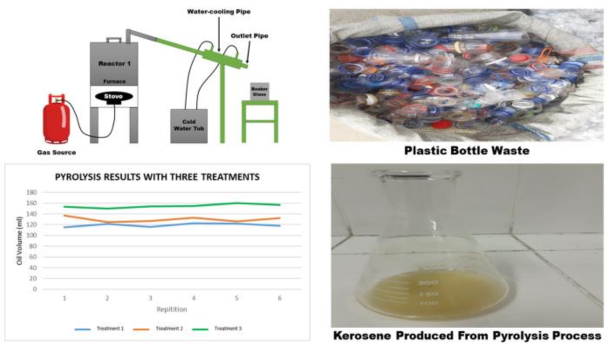
Graphical abstract



Abstract

Plastic waste is harmful to the environment due to its long-term decomposition process. Plastic waste is made out of hydrocarbon polymers, its chain bonds do not naturally decompose physically, chemically, or biologically. The plastic waste generated in Indonesia reaches up to 175,000 tons per day, in the long term effect this will cause environmental problems when not managed properly. The purpose of this study was to determine the effectiveness of a plastic waste pyrolysis reactor with a zeolite catalyst as an appropriate technology in producing kerosene. The samples are plastic bottles waste from the Cimahi campus' area. The results of kerosene production from the first, second, and third treatment were 122 ml, 137 ml, and 160 ml respectively. Based on ANOVA bivariate test, a p-value of 0.00 was obtained, meaning there was a significant average difference in the amount of kerosene produced between each treatment. Based on The LSD Post-Hoc Test, the significance value of the mean between each group was 0.000 ($p<0.05$), meaning there was a significant difference in the average amount of kerosene produced between every treatment group, the most significant difference is within the third treatment by 35.67.

Keywords: Plastic waste, pyrolysis, zeolite, kerosene.

1. Introduction

Modernization requires the use of plastics in everyday life, the tools that we are using are mainly made of plastic such as water buckets, disposable plastic tableware, plastic bottles, and so on. The use of plastics provides convenience and practicality in community activities, be it for primary, secondary, or even tertiary needs. Thus this has impacted the abundant amount of plastic waste generated due to its disposable and practical use in daily life.

One of the individual habits that exacerbate the impact of plastic waste is the unaccustomed effort in sorting out organic and inorganic waste with the 3R (Reuse, Reduce, Recycle) program in the community. This resulted in the abundance of unsorted plastic waste with other waste that has made the waste processing process become more difficult, moreover, the disposal of plastic waste in the landfill pollutes the soil. Plastic wastes are likely to block the infiltration of water into the soil, become pollutant residues, block the passage of rainwater and sunlight, thereby reducing soil fertility, which will eventually cause catastrophic flooding. Burning plastic waste can also cause environmental harm namely air pollution, by producing dioxins which are carcinogens and can cause respiratory problems. Plastic wastes can also cause water pollution when it is disposed of directly into the water bodies and this will harm the aquatic ecosystem.

Plastic waste has a negative impact on the environment due to its long-term decomposition process. Plastic waste is composed of hydrocarbon polymers with chain bonds that are uneasily decomposed naturally either physically, chemically, or biologically (Gnanavel, 2014). The production of plastic waste in Indonesia reaches up to 175,000 tons per day, if not managed properly, in the long-term, the overwhelming waste generation will cause environmental problems. Reducing the use of plastics is still not implemented optimally because the economic and practical alternative substitutes materials for plastics has not been carried out optimally. Efforts to recycle plastic waste will only change plastic waste into a new form aside from reducing the volume of plastic waste itself, when plastic recycling products have lost their function (are not used anymore) they will end up becoming plastic waste again (Wahyudi, 2018).

The development of technology to process plastic waste continues to grow by utilizing plastics that have a fairly high calorific value, equivalent to fossil fuels such as gasoline and diesel. Therefore, it is necessary to have an alternative recycling process that is more promising and prospective. One of them is the effort of converting plastic waste into oil. The waste processing method that can reduce plastic waste generation is the pyrolysis method (Rachmawati, 2015).

Generally, pyrolysis products consist of three types, namely gases such as (H_2, CO, CO_2, H_2O, and CH_4), tar (pyrolytic oil), and charcoal (Ramadhan, 2014). One of the places where plastic wastes have not been processed into oil is in the campus area of Bandung Health Polytechnic, specifically Gunung Batu Cimahi Campus, therefore this research will experiment with processing plastic waste into fuel oil by using a pyrolysis reactor with a zeolite catalyst. The application of the pyrolysis method is expected to reduce plastic waste generation while obtaining economic value from the process.

2. Materials and methods

The type of research used is experimental research, the object of the research is plastic waste generated from Bandung Health Polytechnic, Cimahi Campus. The variables in this research consisted of independent variables, namely pyrolysis with a zeolite ratio of 4%, 6%, and 8% respectively, while the dependent variable is the volume of kerosene and economic valuation.

The conceptual framework for this research is as follows:

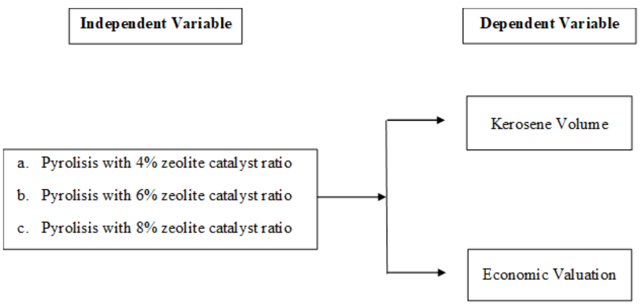


Figure 1. Conceptual framework on the effectiveness of plastic waste pyrolysis reactor with a zeolite catalyst as an appropriate technology in producing kerosene.

The research was carried out in a workshop of the Environmental Health Department Campus of Bandung Health Polytechnic in Cimahi. The preparation and execution of the research were carried out for 8 months, namely in March - November 2020 (Figure 1).

The population in this research includes all plastic wastes generated from Bandung Health Polytechnic, Cimahi Campus offices area. While the samples are some parts that were taken from the total population. The sampling method used is a grab sampling method, where the volume of plastic waste generation is estimated to have met the quantitative requirements for research. The amount of plastic waste (sample) required for the pyrolysis process is calculated based on the number of repetitions carried out in each treatment using the Gomez formula as follows (Gomez, 2013):

$t\,(r-3) \geq 15$

$3\,(r-3) \geq 15$

$3r \geq 18$

$r \geq 6$

Description:

t = Number of Treatments

r = Number of Repetitions

Based on the calculation, the amount of plastic waste required for the research is obtained by multiplying treatments (3) x repetitions (6) x 1 kg = 18,000 grams (18 kg).

2.1. Materials

The materials and the tools needed for the research are 1) Pyrolysis reactor materials that are made out of steel plate, 2) The temperature controller with a high-temperature thermometer sensor mounted on the reactor, 3) The amount of plastic waste required for one cycle of thermal decomposition is 1 kg, 4) The type of plastic waste used is mineral water plastic bottles, 5) The energy source of heat used is liquefied petroleum gas (5,5 kg). The process of using the reactor begins by preparing the tools and materials required, when the tools and materials are well prepared, the plastic waste is then inserted into the pyrolysis reactor, and then prepared for the water-cooled condenser. When everything is set, turn on the energy source to proceed with the thermal decomposition, after a few minutes, observe the increasing temperature at the reactor and condenser, note down the information of time and temperature shown until the oil is discharged from the outlet pipe then accommodates it using a beaker glass. Observe the process thoroughly for approximately one hour until there are no more remaining drops of oil. When everything is done, turn off the energy source and cool down the reactor until it is back to its normal/ safe temperature.

2.2. Methods

The steps carried out in this research are 1) Designing and assembling the pyrolysis reactor, 2) Collecting plastic wastes from Bandung Health Polytechnic, Cimahi Campus area such as from the offices and canteen. 3) Producing kerosene using a pyrolysis reactor with the addition of zeolite as a catalyst. 4) Calculating the volume of kerosene produced. 5) Carrying out a flame test for the produced kerosene.

The Zeolites used were replaced in every single experiment repetition in this study. The zeolite catalyst placed at the end of the outlet pipe affected the clarity level of the oil produced. It also works as a filter for the emitted smoke. The smoke from the usual pyrolysis process was usually thick and harmful because it contains radon as a side effect of the combustion process. On the other hand, by using the zeolite as a filter, the smoke emission decreases, it only comes out a little, and the process runs smoothly (Figure 2).

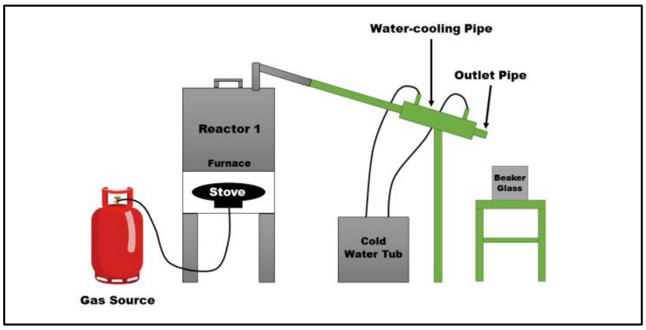


Figure 2. Reactor design.

Data were collected variously such as by measuring the weight of plastic waste that will be processed by pyrolysis, calculating the amount of zeolite required for catalyst, observing the heating temperature in the reactor and condenser, measuring the volume of kerosene produced from each pyrolysis process, and estimating the calculation of the economic valuation by calculating the production cost for one cycle of thermal decomposition until the oil is produced, then finally comparing the economic valuation between the kerosene produced and the benchmark price of kerosene on the market.

The data analysis used in this research is univariate and bivariate analysis. The univariate analysis is used to obtain an overview of the description for each research variable, univariate analysis consists of minimum value, maximum value, and average value. The Bivariate analysis is used to identify the effect of independent variables on each dependent variable using the ANOVA test (Hastono, 2017).

3. Results and discussion

3.1. Pyrolysis results

The results of the research are shown as follows:

Table 1. Pyrolysis results with three treatments

Treatment 1 (4% Zeolite)	Treatment 2 (6% Zeolite)	Treatment 3 (8% Zeolite)
115 ml	137 ml	153 ml
121 ml	125 ml	150 ml
116 ml	127 ml	154 ml
123 ml	133 ml	155 ml
122 ml	126 ml	160 ml
118 ml	132 ml	157 ml

Table 2. Univariate analysis results

Treatments	n	Mean	Std. Deviation
Treatment 1	6	119.17	3.312
Treatment 2	6	130.00	4.733
Treatment 3	6	154.83	3.430
Total	18	134.67	15.789

Table 3. ANOVA test result

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4012.333	2	2006.167	133.349	.000
Within Groups	225.667	15	15.044		
Total	4238.000	17			

Table 4. LSD test result

LSD	**Treatment 1**	Treatment 2	-10.833*	2.239	0.000	-15.61	-6.06
		Treatment 3	-35.667*	2.239	0.000	-40.44	-30.89
	Treatment 2	Treatment 1	10.833*	2.239	0.000	6.06	15.61
		Treatment 3	-24.833*	2.239	0.000	-29.61	-20.06
	Treatment 3	Treatment 1	35.667*	2.239	0.000	30.89	40.44
		Treatment 2	24.833*	2.239	0.000	20.06	29.61

Based on Table 1, The highest amount of kerosene is produced from the first treatment which is 122 ml, as for the second treatment it was 137 ml, and for the third treatment, it was 160 ml.

The percentage of kerosene production from the total pyrolysis process of plastic waste using a zeolite catalyst for the first, second and third treatment resulted in 11,5% up to 12,3%, 12,5% up to 13,7%, and 15,3% up to 16,0% kerosene was produced respectively.

Based on Figure 3, the results show that the volume of kerosene produced from treatment 1 to treatment 3 has increased with a range between 122 ml to 160 ml.

3.2. Univariate analysis results

The results of the univariate test are as follows:

Based on Table 2, the average kerosene production in the first, second, and third treatment is 119,17 ml, 130 ml, and 154.83 ml respectively (Tables 3 and 4).

3.3. Bivariate analysis results

Based on the bivariate test using ANOVA, it was obtained a p-value of 0.00 meaning that there is a significant average difference in the amount of kerosene produced by the pyrolysis process between each treatment.

Based on The LSD Post-Hoc Test, the significance value from the mean between each group was 0.000 ($p < 0.05$), thus there was a significant difference in the average amount of kerosene produced between every treatment group. The most significant difference in the average amount of kerosene production resulting from the pyrolysis process with zeolite as a catalyst is within the third treatment by 35.67.

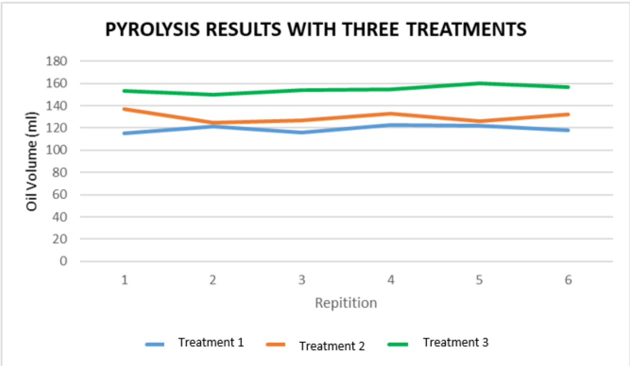


Figure 3 Pyrolysis results with three treatments.

3.4. Economic valuation results

Economic valuation is obtained by converting the thermal decomposition time of 5.5 kg gas for 40 hours divided by one cycle of thermal decomposition (60 minutes) to produce 150 ml of kerosene optimally from 1 kg of plastic.

Based on the data above, the results obtained are 4 hours: 1 hour = 40 times of thermal decomposition with each cycle producing 150 ml so that the total kerosene produced is 40 x 150 ml = 6000 ml. The price of 1 liter of kerosene is Rp. 11,200 so the total economic valuation is 6 Liters x Rp. 11,200 = IDR 67,200. The economic valuation is that the price was IDR 10,000 higher than 5 kg cylinder gas which cost IDR 57,500. The pyrolysis process is also beneficial in addressing the plastic waste problem that could harm the environment if left unsolved.

4. Discussion

The type of waste used as the raw material for pyrolysis is plastic waste from mineral water plastic bottles, the plastic waste type is PET (Polyethylene terephthalate) this plastic is colorless or clear. This type of plastic waste is difficult to decompose naturally, so other processes are required to transform it into useful products. The pyrolysis process is suitable for processing plastic waste into kerosene so that it can reduce the risk of environmental pollution due to plastic waste.

The pyrolysis process in this study started at a temperature of 54°C dripping oil after burning for 22 minutes, burning for 32 minutes produced 115 ml of oil for a combustion period of 45 minutes to 60 minutes. The temperature of 92.6°C began to flow rapidly, the burning time was 39 minutes. The water temperature in the condenser ranges from 11.7°C to 14.8°C. This temperature can change the gas phase into a liquid phase so that oil is produced from the pyrolysis process.

The zeolite catalyst placed at the end of the outlet pipe affects the clarity level of the oil produced and also act as a filter for the smoke produced, other pyrolysis reactors without zeolite are most likely to pollute the air with the thick smoke and the possibility of harmful radon existence in the gas emission from the thermal decomposition process, however by using zeolite as a filter, there are only a little of smoke produced and the process runs smoothly.

This is possible because zeolite has the property of releasing water easily when heated, but can also easily rebind water molecules in humid conditions. The pore structure of the zeolite also has a role as a microreactor so that the catalytic process runs optimally. The reactor in this research uses plastic waste as a form of feed which will be inserted into the reactor and then closed and heated. The output will continue to flow during the thermal decomposition process to the cooling pipe section, after passing through the condenser, the condensed gas will turn into oil.

The results of this study are in line with the previous research conducted by Endang which stated that the LDPE plastic pyrolysis process can produce 37.5% oil from 500 grams of LDPE plastic, and it's also in line with research conducted by Rachmawati which stated that the pyrolysis process of plastic waste HDPE produces 15.49% oil from 500 grams of plastic waste processed by pyrolysis while for PET type plastic waste produces 18.18% oil from 500 grams of plastic processed by pyrolysis. The difference that occurs is that when using a zeolite catalyst, the oil starts to form at the temperature of 54°C while those without zeolite catalysts can only start to form oil at 200°C and this will eventually affect the use of fuel in the pyrolysis process.

Catalytic pyrolysis can increase the oil produced because the acidic conditions of the catalyst will increase the cracking of lignocellulose into simple compounds, besides the pore size of the zeolite can affect the selectivity of the compound. Compounds resulting from thermal cracking which have a molecular size smaller than the zeolite pores can then enter the pores and produce products according to the zeolite pore size. Active zeolites increase the cracking reaction which results in more long-chain hydrocarbons being split into short-chain hydrocarbons so that more bio-oil is produced.

The use of zeolite catalysts in the pyrolysis process can break down the hydrocarbon chain thoroughly and quickly so that the temperature does not need to be too high, this is because at the temperature of 54°C, the oil has formed as a result of pyrolysis. The zeolite catalyst used in pyrolysis will prevent the formation of all dioxins and furans (Panda, 2010), this is in line with the results of research that showed the smoke produced tends to be small in amount and does not smell like gases.

5. Conclusions

The conclusions of this research are:

1. The average total production of kerosene from pyrolysis results in the first, second, and third treatment is at 122 ml, 130 ml, and 157 ml respectively.

2. There was a significant difference in the average amount of kerosene production in the pyrolysis reactor with zeolite catalyst.

3. The Economic valuation from the amount of kerosene produced out of 18 kg of plastic waste, is as much as 6 liters, thus the total economic valuation is Rp. 67,200.

6. Suggestions

1. Larger scale of pyrolysis reactor is required so that the greater economic value will be obtained from the amount of kerosene production.

2. Further research is required regarding the optimum temperature in the water-cooled condenser for the formation of pyrolysis kerosene, the calorific value of the oil, the type of gas produced, and the type of plastic waste used.

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