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Research Article

The effect of temperature and pyrolysis time of plastic waste in producing methane

Holisha Widiyanto, Boima Situmeang, Dina Alva Prastiwi, Ninik Triayu Susparini, and Isna Laitusholihah

Department of Chemistry, Sekolah Tinggi Analis Kimia Cilegon, Cilegon 42411, Indonesia

Corresponding author: Holisha Widiyanto (holisha.widiyanto@gmail.com)

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Keywords

Methane gas
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Abstract

Plastic waste is a major environmental problem due to its widespread presence and lack of economic value. Pyrolysis is a process that can decompose plastic waste and produce methane gas, liquid, and solid products. This study aimed to investigate the factors that affect methane gas production and the amount of methane gas produced during the pyrolysis of various plastics, including a black plastic bag and plastic with aluminium foil. The results showed that the aluminium foil plastic produced more methane gas than the black bag, with optimal gas content at 7.74% for the aluminium foil plastic and 3.48% for the black bag. The type of plastic, time, and temperature all significantly affected the yield of methane gas produced. In addition, the interaction between variables in plastic type, time and temperature greatly affects the yield of methane gas (CH_4) obtained, because the type of plastic F count (2904) is higher than F table 0.05 (4.00), at temperature F count (5449) is greater than F table 0.05 (2.76), when F count (746) is greater than F table 0.05 (2.76). In conclusion, the snack foil produced more methane gas than the black bag because it was made of low-density polyethylene and contained aluminium ions that catalysed the decomposition of the material, resulting in an increase in the amount of methane gas produced.

Introduction

Plastic garbage is a severe environmental issue that needs to be addressed. The processing of enormous volumes of plastic garbage presents numerous challenges (Rachmawati and Herumurti, 2015). The operational costs are rising along with the volume of plastic waste, which makes disposal more challenging (Naufan, 2016). When compared to organic garbage, the contribution of plastic waste is relatively large. National plastic trash can amount to 14.7% in a year (Kholidah et al. 2018). In Indonesia, landfilling or burning are the current methods used to handle plastic trash. This method cannot totally decrease and eliminate plastic trash; in fact, due to inappropriate handling, it may even result in new environmental problems (Bokof et al. 2021).

Aerated digestion, gasification, sanitary landfill technology, incineration, and other processes are only a few of the technologies used to manage plastic trash in developed nations. Pyrolysis is a currently very promising method of treating plastic waste (Wardhana and Saptoadi, 2016). Recycling plastic trash into fuel is possible using the pyrolysis process. When plastic-forming polymers are broken down using heat from a solid in the absence of oxygen, many thermochemical conversion processes can take place, resulting in the production of gases (hydrocarbons and other types), liquids (pyrolytic liquid), and solids (Charcoal) (Juliastuti, 2013).

Pyrolysis is a method to lessen plastic waste and will also yield a lot of energy. Typically, 1 kg of polyolefin plastic waste, such as polypropylene, polyethylene, and polystyrene, requires 950 ml of fuel oil to be produced from plastic trash using the pyrolysis method (Thorat et al. 2013; Harefa et al. 2021). Polyethylene

(HDPE and LDPE) makes up 46% of plastic trash, followed by Polypropylene (PP), Polystyrene (PS), Polyvinyl Chloride (PVC), Polyethylene Terephthalate (PET), Acrylonitrile-Butadiene-Styrene (ABS), and other polymers, at 16%, 16%, and 7%, respectively (Praputri et al. 2016). For this study, aluminium foil- and black crackle-containing material made of polyethylene was used (as food packaging).

Pyrolysis produces 3 products namely gas, liquid and solid. In this study, the pyrolysis product will be taken in the gas form. The aim of this pyrolysis process is to find alternative energy sources and the utilization of plastic waste to produce methane gas (CH_4) (Nasrun et al. 2015). The study was made in order to determine the content of methane gas (CH_4) as an alternative source of energy using gas chromatography (GC).

Method

Materials and equipment

The materials used in this study were two types of plastic waste, i.e., black plastic waste and snack plastic waste containing aluminium foil, and methane gas standard 100 ppm (liquid water gas standard). This study also used equipment including pyrolysis equipment, 250 ml Erlenmeyer (Pyrex) and GC (Shimadzu 14B).

Raw material preparation

Plastic waste was obtained from the trash cans around Gerem Raya residents RT 02/04. After being collected and separated between the black plastic and the plastic containing aluminium foil, the washing process was carried out with water to remove the dirt on the plastic. The plastic waste was then dried and cut to a size of 5-10 mm.

Pyrolysis process

Pyrolysis process conducted by weighed 350 g of clean plastic waste and then put into a retort with a diameter of 10.9 cm and a height of 19.7 cm. The cooling water was run and the heater was turned on. The retort was heated up to the desired temperature and then the temperature was maintained constant. The pyrolysis process was carried out at atmospheric pressure. When the desired pyrolysis process was reached, it was considered as the initial reaction which was then measured. The pyrolysis process was stopped after 30 minutes. Pyrolysis process was also conducted with different variables (Salwan et al. 2015).

Methane gas analysis (Chromatography gas)

The syringe was rinsed with the sample, take a sample of 400 l of gas injected using a syringe into the gas chromatography for 10 minutes to determine the content of methane gas (CH_4).

Data analysis method

The data analysis method in this study used a factorial randomized design. The experimental design used in this study are:

$$Yijk = \mu + Ai + Bj + ABij + Ck + ACik + BCjk + ABCijk + \varepsilon ijk \qquad (1)$$

Information:

Yijk : The observation mean value from the concentration group that obtained treatment to storage time.
μ : The general average value.
Ai : Effect of i level factor Type of plastic
Bj : Effect of j level temperature factor
Ck : Effect of k level Time factor
ABCijk : Interaction effect between i level factor type of plastic, j level factor Temperature and k level time factor
εijk : Effect of the k experimental unit in the treatment combination (ijk)

A diversity analysis (ANOVA) was carried out to determine the effect of treatment. Analysis of diversity using the following test criteria:

a. If count F is smaller than table F then Ho is accepted or the treatment has no effect on a confidence interval.
b. If count F is greater than table F then Ho is rejected or the treatment has an effect on a confidence interval.

Furthermore, to find out the influencing factors, the ANOVA test was continued with the DUNCAN distance test.

Results and Discussion

This research used two types of plastic in the pyrolysis process: black plastic bags and aluminium foil plastic (as snack packaging). It was conducted to determine the content of methane gas (CH_4) produced in the pyrolysis process. Based on the research, black plastic bags and aluminium foil plastic (as snack packaging) have different content of methane gas (CH_4). It was from the type of plastic, temperature, and time of the pyrolysis process. A table of the content of methane gas (CH_4) is shown in Table 1. Based on the result of the research, it was obtained methane gas (CH_4) from the pyrolysis process shows that the content of methane gas (CH_4) produced by black plastic bag types is less than with aluminium foil type plastic (as snack packaging).

Table 1. Measured methane gas from black plastic bags and aluminium foil plastic through a period of time using pyrolysis

Plastic-type	Temperature (°C)	Time (m)			
		0	10	20	30
Black Plastic Bags	100	0.000457	0.000923	0.001407	0.001527
	150	0.001630	0.002460	0.002733	0.003463
	200	0.103890	0.142820	0.147163	0.154997
	250	0.128183	1.060423	3.347293	3.475727
Aluminium Foil Plastic	100	0.022617	0.035323	0.042553	0.060260
	150	0.152300	0.211650	0.292673	0.474690
	200	1.123153	1.542823	1.878413	2.215483
	250	2.236530	3.741917	4.403080	7.742787

Aluminium foil-type plastic contains the element aluminium (Al). This aluminium (Al) is a catalyst of the pyrolysis process, so the methane gas content (CH_4) obtained in aluminium-type plastic is relatively high compared to the methane gas content (CH_4) in a black plastic bag. The temperature and time significantly affect the content of methane gas (CH_4). The higher the pyrolysis temperature and the longer the pyrolysis time, the content of methane gas (CH_4) produced from the pyrolysis process are many more.

Effect of temperature on methane gas production

Fig. 1 shows that the concentration of methane gas (CH_4) against the temperature obtained in the plastic pyrolysis process is between 2 types of plastic, namely black plastic bag and aluminium foil plastic, where the optimal condition is at a temperature of 250°C.

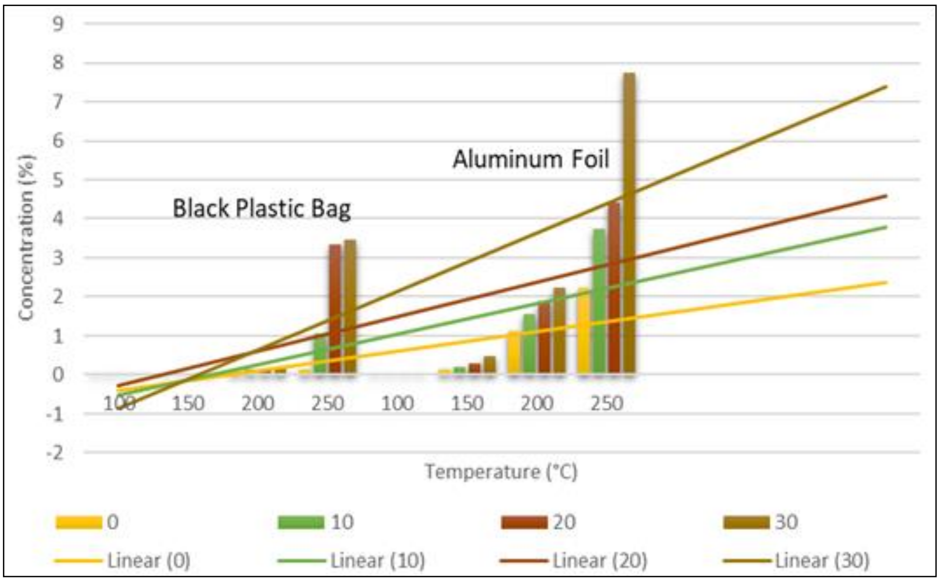

Figure 1. Graph of methane gas concentration (CH4) against temperature (°C)

Fig. 1 also shows that aluminium foil has a higher degree of methane gas production from pyrolysis compared to black plastic bag. Both materials consisted of low-density polyethylene which means the amount of the polymer itself will make the difference whereas considering the result on Fig. 1 the snack foil has more polymer compared to the black bag. Increase in temperature did affect the gas concentration as the research by Fuchs et al. (2016) stated that temperature does increase the production of methane gas.

Effect of time on methane gas production

Fig. 2 shows that the concentration of methane gas (CH_4) against the time obtained in the plastic pyrolysis process is between 2 types of plastic, namely black plastic bag and aluminium foil plastic, where the optimal conditions for the black plastic bag pyrolysis process are at 20 and 30 minutes at 250°C.

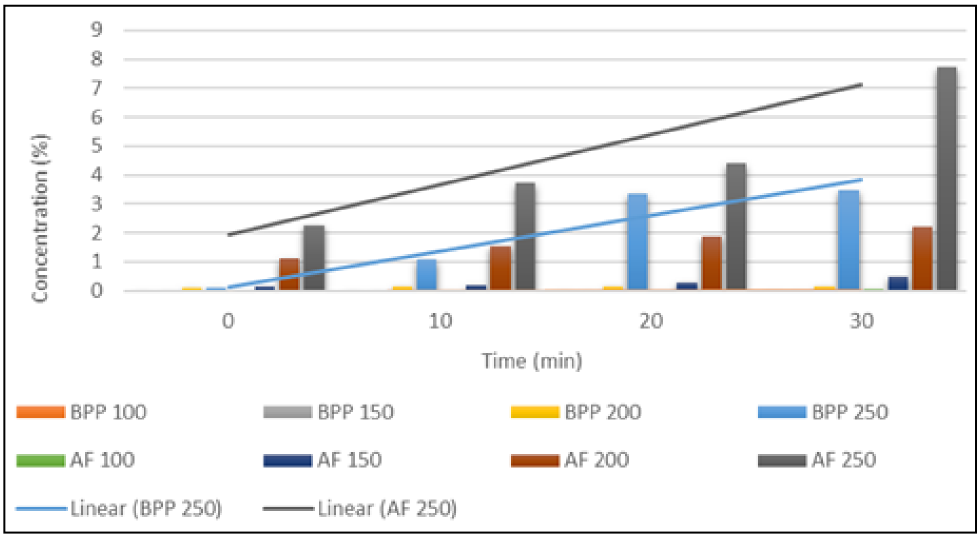

Figure 2. Graph of methane gas (CH4) concentration against time (minutes)

Furthermore, on aluminium foil, the optimal condition is 30 minutes at a temperature of 250°C. The trendline from the chart can be read as an increased trend overtime and temperature thus aligned with the research done by Kida et al. (2022). The research by Royer et al. (2018), which found that methane gas production increases with longer incubation times, corroborated the methane gas produced as a result of the temperature increase. To make up for the longer incubation times, the method was modified to use higher temperature rather than air incubated at room temperature to stir up more molecular movement. In order to determine how the factors affected the research that was done, an analysis of variance was carried out. The technique employed is a Factorial Completely Randomized Design (CRD) method using two plastic-type factors, each with two levels and three replications: a temperature factor and a time factor.

Table 2. Analysis of Variance (ANOVA)

Variation	DK	JK	KT	F count	F table(α=95%)
Average	1	113.22	113.22		
Plastic type (A)	1	29.04	29.04	2904.00*	4.00
Temperature (B)	3	163.47	54.49	5449.00*	2.76
time (C)	3	22.37	7.46	746.00*	2.76
AB	3	24.25	8.08	808.00*	2.76
AC	3	3.34	1.11	111.00*	2.76
BC	9	44.51	4.95	495.00*	2.04
ABC	9	5.74	0.64	64.00*	2.04
Mistakes	64	0.70	0.01		
Amount	96	406.63			

Table 2 demonstrates that, with a 95% confidence interval of 4.00, the calculated F for the plastic type factor (A) in the ANOVA table is 2904.00, which is higher than the F table. It demonstrates how the amount of methane gas (CH_4) produced during the plastic pyrolysis process varies depending on the type of plastic used. The computed F for the temperature variation (B) is 5449.00, which has a 95% confidence range of 2.76 and is more significant than the F table. It demonstrates how the temperature variable impacts the amount of methane gas (CH_4) produced during the pyrolysis of plastic. With a 95% confidence interval of 2.76, the calculated F for the time variation (B) is 746.00, which is higher than the F table. It demonstrates how the time variable influences the levels of methane gas (CH_4) produced during the pyrolysis of plastic. Plastic type and temperature resulted in a F count of 808, which, with a 95% confidence interval of 2.76, is higher than the F table. It demonstrates how different plastic types and temperatures have an impact on the amount of methane gas (CH_4) produced during the plastic pyrolysis process. With a 95% confidence interval of 2.76, the kind of plastic and the time obtained by the computed F of 111.00 are greater than those in the F table. It demonstrates how the amount of methane gas (CH_4) produced during the plastic pyrolysis process depends on the kind of plastic and the amount of time. The computed F at these conditions is 495.00, which, with a 95% confidence interval of 2.04, exceeds the F table. It demonstrates how the factors of temperature and time impact the amounts of methane gas (CH_4) produced during the pyrolysis of plastic. With the factors of plastic type, temperature, and duration, a F count of 64.00 was produced, surpassing the F table with a 95% confidence interval of 2.04. It shows that the variables of plastic type, temperature, and time affect the levels of methane gas (CH_4) in the plastic pyrolysis process.

Conclusion

According to the research, the interplay between the type of plastic, temperature, and duration has a substantial impact on the yield of methane gas (CH_4) produced during this pyrolysis process. With a mass of 300 g of two types of plastic, different levels of methane gas (CH_4) were produced; the best result for the type of black plastic bag was produced at a temperature of 250°C at 30 minutes at 3.47%, while the best result for the type of aluminum foil plastic (snacks) was produced at 250°C at 7.74%, demonstrating how the different types of plastic significantly affect the outcomes of methane gas (CH_4).

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