CHEESA: Chemical Engineering Research Articles
ISSN **2614-8757 (Print)**, ISSN **2615-2347 (Online)**
Available online at: http://e-journal.unipma.ac.id/index.php/cheesa

Research Article

Analysis of Pyrolytic Product Distribution for B3 and Non-B3 Medical Waste Pyrolysis

Analisis Distribusi Produk Pirolitik pada Pirolisis Limbah Medis B3 dan Non-B3

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Received: 14 October 2022; *Revised: 08 December 2022;* *Accepted: 09 December 2022;*	***doi:*** *10.25273/cheesa.v5i2.14134.101-110*

Abstract

The coronavirus disease (COVID-19) has badly impacted many sectors, particularly medical waste generation in healthcare facilities. The increasing amount of medical waste poses a serious threat to health and environmental sustainability. Pyrolysis as a superior thermochemical technology is an effective solution for treating both B3 medical waste and non-B3 medical waste. The waste used in this study has good characteristics, as indicated by the low water and high fixed carbon content. The pyrolysis process yields products with economic value, such as solid, liquid, and gas products. Therefore, this study aims to determine the levels of products that can be produced from B3 and non-B3 medical waste. The results showed that rubber bands produce the highest proportion of liquid products at 44%, the highest solid products were obtained from LDPE plastic waste with a proportion of 65%, while the highest gas product was produced by mask waste at 45%. Based on the results, waste with high product yields can be used as an alternative energy source, such as gasoline, LPG, briquettes, and battery-based materials.

Keywords: alternative energy; medical waste; pyrolysis; thermal technology

Abstrak

Virus corona (COVID-19) memberikan dampak buruk bagi banyak sektor, terutama pada timbulan sampah medis di fasilitas pelayanan kesehatan. Meningkatnya jumlah limbah medis merupakan ancaman serius bagi kesehatan dan kelestarian lingkungan. Pirolisis sebagai teknologi termokimia yang unggul merupakan solusi efektif untuk pengolahan limbah medis baik limbah medis B3 maupun limbah medis non-B3. Sampah yang digunakan dalam penelitian ini memiliki karakter sampah yang baik. Hal ini ditunjukkan dengan kadar air yang rendah dan kadar karbon tetap yang tinggi. Tujuan dari penelitian ini adalah untuk mengetahui kadar produk yang dapat dihasilkan dari limbah medis B3 dan limbah medis non-B3. Hasil penelitian diketahui karet gelang menghasilkan proporsi produk cair tertinggi sebesar 44%, sedangkan produk padat tertinggi diperoleh dari limbah plastik LDPE dengan proporsi 65% dan produk gas tertinggi diperoleh dari limbah masker dengan proporsi 45%. Limbah dengan hasil produk yang tinggi memiliki potensi untuk dimanfaatkan sebagai sumber energi alternatif seperti bensin, gas lpg, briket dan bahan dasar baterai.

Kata kunci*: energi alternatif; limbah medis; pirolisis; teknologi termal*

1. Introduction

Coronavirus disease 2019 (COVID-19) is a deadly virus whose existence was first reported in Indonesia in March 2020. Subsequently, census information on the number of people who have contracted and recovered from the disease has been integrated into statistical data comprehensively by various credible public or private institutions to increase public awareness. Similar information related to the census of medical waste, which is also important must be given more attention by the community. This will reduce the increasing impacts of medical waste generation. Previous data on medical waste showed an increase in the capital city of DKI Jakarta from March 2020 to July 2021, with a total of seven to ten thousand tons. This includes masks, gloves, bandages, tissues, plastic, paper, syringes, personal protective equipment (PPE), and patient food waste [1]. The World Health Organization [2] stated that medical waste is a hazardous material containing radioactive, toxic, or infectious substances. Medical waste management should be performed using safe and environmentally friendly methods [3].

Several management practices related to technology, such as chemical disinfection, sanitary landfill, incineration, and pyrolysis, have emerged in various developed and developing countries [4,5]. Indonesia, as a developed country, prefers incineration which has the advantages of reducing the capacity and quantity of waste significantly and sterilizing them as a whole [6]. However, organic wastes such as polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), polycyclic aromatic hydrocarbons (PAHs), inorganic emissions, as well as ash containing toxic metals are generated during waste incineration. They cause secondary pollution to the environment, which threatens human health [7,8].

Thermochemical conversion has many advantages over traditional waste incineration methods, which are mainly related to increased air pollution, generation of value-added products, and energy [5]. Another advantage is that the operation uses a temperature which can be adjusted as needed, thereby potentially reducing the risk of alkaline volatilization [9]. One of the thermochemical conversions which utilize the instability of organic components in medical waste is the pyrolysis method [10]. This method uses raw materials that are heated at high temperatures under low oxygen conditions and produces synthetic gas (syngas), which is then condensed and converted into pyrolysis oil. The liquid product has properties that are very close to commercial transportation fuels which can be improved and modified to become an alternative energy source [11].

Previous studies have assessed the pyrolysis concept as the most appropriate method for treating medical waste because it is considered safe and environmentally friendly [5,8,12]. Medical waste generated by health services consists of 15% B3 medical waste which comprises hazardous and toxic materials, while the remaining 85% is considered non-B3 [13]. Non-hazardous medical waste resembles domestic/household materials, such as garden waste, food scraps, paper, plastic, cloth and rubber. Meanwhile, B3 medical waste such as medical masks and gloves arising from hospital medical activities, are pathogenic and infectious in nature [13]. Based on the explanation above, this study aims to perform pyrolysis of B3 and non-B3 medical waste to determine the levels of products in the form of liquid, solid, and gas products. The results are expected to be used as an innovation in handling B3 and non-B3 medical waste in Indonesia.

2. Research Methods

2.1 Tools and materials

The raw materials were obtained from the nearest canteen and pharmacy around the Universitas Muhammadiyah Riau, between May and July 2022. They consist of B3 and non-B3 medical waste. B3 medical waste includes masks and gloves, while non-B3 includes rubber bands, LDPE plastic, HVS paper, cotton cloth, garden and food waste. The sample weight was determined by keeping half of the reactor volume (500 mL) which was then weighed. The proportion of each waste was placed in the reactor, as shown in Figure 1. Furthermore, the food waste in this study was dried beforehand at a temperature of 90 °C to get the maximum bio-oil and reduce the water content [14]. The next step is the enumeration process. The collected waste was chopped to a size of 5 mm to maximize waste in the heating furnace and accelerate thermochemical reactions [15].

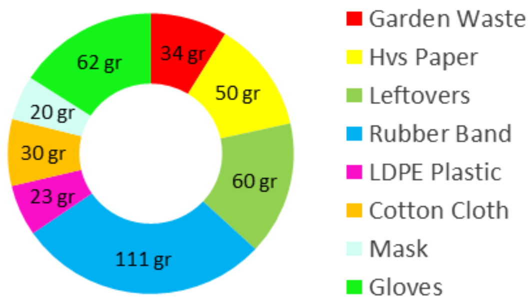
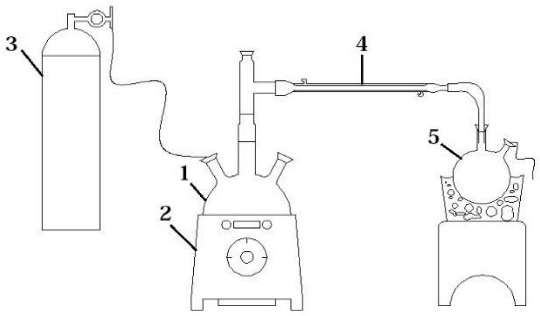


Figure 1. The proportion of medical waste

The laboratory-scale pyrolysis equipment consisting of several components was used as shown in Figure 2. The chopped medical waste was placed into the neck flask reactor 3 (1) which has a volume of 1000 mL. The heating furnace (2) is a horizontal frequency electromagnetic heating device with an inner diameter of 106 mm, a height of 61 mm, and is equipped with a temperature controller (30-450 °C). Nitrogen (3) was fitted with a hose and regulator to adjust the nitrogen flow rate, while the condenser (4) used was a Liebig-type with a length of approximately 60 cm that utilizes the flow rate of tap water as a cooling source. Meanwhile, the liquid product container (5) used was a glass two-neck flask with a volume of 500 mL.



(1). Reactor (2). Electromagnetic heating furnace (3). Nitrogen (4). Condenser (5). Liquid product container

Figure 2. Pyrolysis equipment schematic

2.1.1 Characteristics of Medical Waste

A feasibility test for B3 and non-B3 medical waste is an important step before performing the pyrolysis process. The characteristics of medical waste were determined using the proximate test based on ASTM D 1762-84 standardization. The proximate test was used to determine the content contained in B3 and non-B3 medical waste. This includes water, ash (fly ash), volatile, and fixed carbon [16].

2.2 Procedure

The first step before the pyrolysis process is to ensure that all equipment sets are properly installed. Chopped B3 and non-B3 medical waste were put in the reactor which was placed into a heating furnace with the temperature set at 400 °C. The pyrolysis time starts counting after the heating temperature is set and turned on. Furthermore, nitrogen was added to help push the syngas out through the condenser pipe at a flow rate of 0.5 L/min. Nitrogen also has the function of minimizing the presence of air in pyrolysis equipment. Airtight conditions can help the pyrolysis process break down complex hydrocarbon compounds into smaller molecules [5].

The cooling system uses two stages, the first is a source of water that flows into the condenser, while the second is a mixture of ice and salt, which is placed under the liquid product collector. Liquid components were separated from volatile products by condensation and collected in specific devices, the solid product was obtained from the pyrolysis residue, while non-condensable gas flowed through the exhaust hose. Furthermore, the process continued until the temperature reached 400 °C. The pyrolysis time and equipment were stopped when no more syngas and liquid were produced. These steps were carried out for all samples of B3 and non-B3 medical waste.

The products obtained from the pyrolysis process were mainly solid (charcoal), liquid (oil) and gas. The percentage of each product produced was calculated using equations 1, 2, and 3.

The liquid product was collected in an oil reservoir under the condenser, and the percentage yield was calculated using equation 1.

$$\%Liquid = \frac{Liquid\ mass}{Initial\ mass} X\ 100\% \quad \text{.........(1)}$$

The solid product (charcoal) is the combustion residue produced through the pyrolysis process and collects in the reactor. The percentage can be calculated using equation 2.

$$\%Charcoal = \frac{Charcoal\ mass}{Initial\ mass} X\ 100\% \quad \text{.....(2)}$$

Gas is the result of a pyrolysis process that cannot be condensed. The gas product from each raw material can be calculated using equation 3.

$$\%Gas = 100 - \%Liquid - \%Charcoal \quad \text{......(3)}$$

Table I. Proximate Test Results

Waste	Water Content (%)	Volatile Content (%)	Ash Content (%)	Fixed Carbon (%)
Mask	2.24	63.85	15.38	18.52
Gloves	2.31	68.08	13.37	16.22
Garden Waste	6.95	64.11	24.15	4.77
Leftovers	26.95	70.06	2.51	0.47
HVS Paper	3.02	65.54	19.20	12.23
Cotton Cloth	10.01	80.40	5.09	14.51
Rubber Band	1.20	60.26	18.97	20.76
LDPE Plastic	5.38	89.62	4.32	0.66

3. Results and Discussion

3.1 Characteristic Test Results

The results obtained for the water, ash, volatile, and fixed carbon test for B3 and non-B3 medical waste are shown in Table I. B3 medical waste including gloves and masks had an average water content of 2.27%, while non-hazardous medical waste such as garden and food waste, paper, rubber, cloth, as well as LDPE plastic had an average water content of 8.91%. High water content is an unwanted substance during the pyrolysis process. This is because it can increase the need for heat and slow down the process. The B3 and non-B3 medical waste had a water content below 10% meaning that they have the potential to be processed by the pyrolysis method based on Silva et al. [17].

B3 medical waste had an average ash content of 14.37%, while that of non-B3 was 12.37%. Ash content is an impurity for the product obtained during pyrolysis and it has non-flammable properties. Therefore, high content will reduce the performance of the pyrolysis tool. The samples used in this study had an ash content below 15% which implies that the waste will have production effectiveness when processed by the pyrolysis method [17].

Volatile contents are substances that easily evaporate and they determine the burning ability of fuel [18]. Gloves and masks have an average volatile content of 65.96%, while that of garden and food waste, paper, rubber, cloth, as well as LDPE plastic was 71.66%. The sample used in this study had a volatile content below 76% indicating that they have good potential to be processed by pyrolysis, according to Liu et al. [19].

Meanwhile, fixed carbon is the remaining amount left after the volatile and ash content test. It is an important component of waste because high fixed carbon indicates the potential to be used as an energy source [18]. Gloves and masks have an average fixed carbon value of 17.37%, while that of garden and food waste, paper, rubber, cloth as well as LDPE plastic was 8.91%. The higher the fixed carbon content produced, the higher the potential for the waste to be used as an energy source.

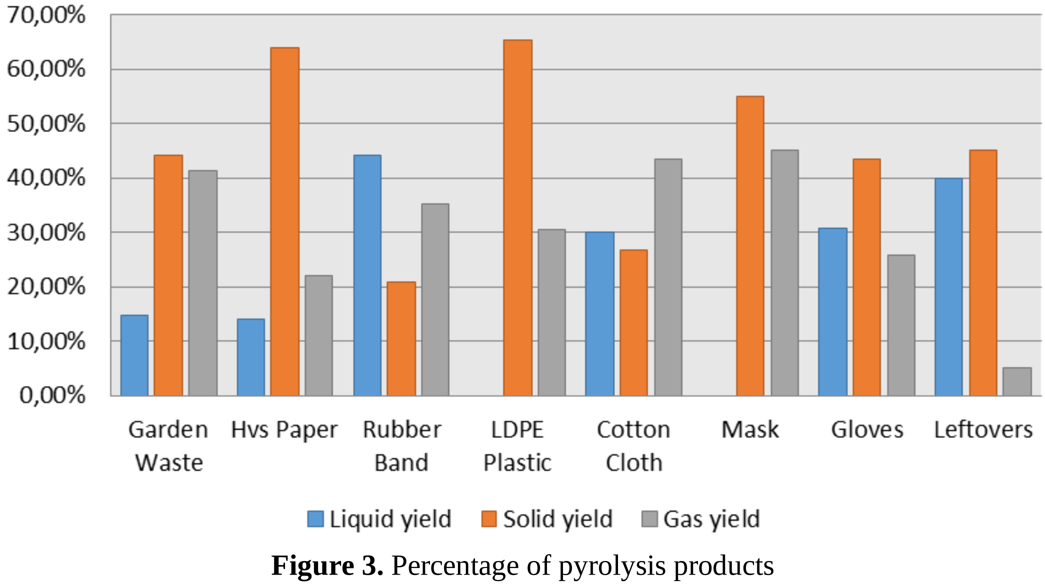


Figure 3. Percentage of pyrolysis products

3.2 Pyrolysis Product Results

The pyrolysis process produces liquid, solid, and gas products as shown in Figure 3. Based on the results, gloves produced liquid, solid, and gas products at 400 °C with a trial time of 90 minutes. The liquid product has a thick texture caused by the aromatic compounds contained in the glove. The highest product obtained was 43% solid, 30% liquid, and 25% gas. A glove (medical glove) is a plastic polymer of the nitrile rubber type. Therefore, the identified medical plastics can be recycled into fuel energy because they are thermoplastic polymers with a high oil content [20].

The mask produced wax, solid, and gas with a trial time of 110 minutes, while the highest product was 55% solid and 45% gas. This waste is made of polypropylene containing paraffin [21] which causes the liquid product to freeze and form wax. The pyrolysis of disposable face mask waste at low temperatures ranging from 350-450 °C will produce wax and light liquid products, while at high temperatures between 450-600 °C, gas and liquid products will be obtained [22]. In this study, masks pyrolyzed at 400 °C did not produce liquid products due to the low temperature.

The residues produced liquid, solid, and gas products with an experimental time of 75 minutes. The highest product from food waste was 45% solid, 40% liquid, and 5% gas. A similar result was found in a study conducted by Amrullah et al. [23] who obtained a solid product of 57% and a liquid of 41% at a temperature range of 400 °C. This is because the high water content in the food waste caused the heating in the reactor flask to slow down, leading to an increase in solid products.

Garden waste produced liquid, solid, and gas products with an experimental time of 60 minutes. Based on the results, the highest product was 44% solid, 15% liquid and 41% gas. A similar result was also obtained from the pyrolysis of leaf and twig waste by Novita et al. [24] namely 35% solid, 30% liquid and 35% gas product at a temperature range of 400 °C. Furthermore, the content of lignin, cellulose and water in garden waste causes gas and solid products to increase [25]. According to Shen et al. [26], the liquid product can be increased [26]by reducing the particle size to 0.3-1.3 mm. This size is smaller than the size used in this study, which is 5 mm.

HVS paper was found to contain liquid, solid, and gas products with a trial time of 60 minutes. The highest product was 64% solid, 14% liquid, and 22% gas. Paper is made from cellulose which is found in wood. The high cellulose content causes an increase in solid pyrolysis products [27]. The liquid product can be increased by reducing the particle size, according to a review by Guedes et al. [28].

Furthermore, cotton fabrics produced liquid, solid, and gas with a trial time of 30 minutes. The product obtained included 30% liquid, 27% solid, and 43% gas. A similar result was also obtained in the pyrolysis of cotton fabric by Ma et al. [29] which produced a liquid product of 24% in the temperature range of 400-500 °C. Cotton fabric is a textile product made from cotton fiber. It has the property of absorbing water (hygroscopic) and heat resistance. The temperature setting of 400 °C in the pyrolysis process is considered capable of degrading cotton fabric waste into liquid products.

Rubber bands were found to contain liquid, solid, and gas products with an experimental time of 108 minutes. The highest product was 44% liquid, followed by 21% solid and 35% gas. Rubber bands have the highest proportion of liquid products because they contain 80% pure rubber, 3% protein, and 2% fatty acids. Moreover, Aragaw and Mokenenen [20] stated that rubber-based waste contains high oil.

LDPE plastic produced wax, solid, and gas products with a trial time of 130 minutes. Based on the results, the highest product was 65% solid and 30% gas. The TPA (Terephthalic Acid) content and the high calorific value of plastic waste cause the combustion process to occur faster and produce more wax. Furthermore, the TPA is sublime and molecules from its isomer which are burned into gas will experience freezing in the reactor flask and condenser, eventually forming a solid wax [30]. Another factor that caused the formation of wax solids is the low-temperature setting [22] which greatly affects the products obtained from plastic waste [31]. The results of liquid products in this study are shown in Figure 4.

Figure 4. Pyrolysis liquid product

3.3 Potential Energy

Products obtained from the pyrolysis process offer many opportunities to be exploited. According to Czajczyńska et al. [14], the liquid product from the pyrolysis of paper biomass, cotton cloth, as well as garden and food waste consists mostly of acids, sugars, alcohols, ketones, aldehydes, phenols, furans, and other mixed oxygen compounds. Meanwhile, glove and rubber band waste contains isoprene, toluene, xylene, trimethylbenzene, and limonene. The liquid product has the potential to be used as an alternative fuel because it has a high calorific content and value. Surono and Ismanto [32] determined the calorific value of liquid products produced from the pyrolysis of PET, PP, and PE plastic waste. The result showed that PP-type plastic has a high heating value of 46.5 Mj/kg. This calorific value is equivalent to those of premium gasoline with a value of 44.0 Mj/kg.

According to Czajczyńska et al. [14], gas products from HVS paper biomass waste, cotton cloth, as well as garden and food waste consist of CO, CO_2, and light hydrocarbons. Meanwhile, products from rubber band waste, LDPE plastic, gloves, and masks contain CO_2, ethane, propane, paraffin, olefin, and carbon. The gas product produced in this study has an average of 30.75% and is considered to have great potential as an alternative gas fuel to replace LPG, in line with Klinghoffer and Castaldi [33].

The pyrolysis process is usually maximized to obtain liquid and gas, while solid products or charcoal are produced from the rest of the combustion process. Besides, the solid products contain a matrix rich in activated carbon content [34] and are widely used as solid fuel briquettes[35] or as a base material for batteries [36].

4. Conclusion

The pyrolysis process in this study produced liquid, solid, and gas products using the same temperature of 400 °C. The highest liquid product was obtained from non-B3 rubber band medical waste with a yield of 44%. Furthermore, liquid products were not obtained from LDPE plastic and masks because the content in the waste does not match the temperature applied, hence, only solid wax was produced. The highest solid product was obtained from LDPE plastic waste, with a yield of 65%, while the lowest was produced from rubber band waste with a yield of 21%. Moreover, the highest gas product was obtained from mask waste, with a proportion of 45% while the lowest was produced from food waste, with a yield of 18%.

Products from the pyrolysis process offer many opportunities to be used as alternative energy sources. Based on the percentage yields obtained, the liquid product with the greatest potential to be converted into gasoline is the rubber band waste with a yield of 44%. The gas products with the best potential to be converted into fuel was obtained from masks with a percentage of 45%. Finally, LDPE plastic waste with a yield of 65% has the greatest potential to be converted into solid fuel briquettes and battery base materials.

Suggestion

Future studies should pay more attention to the characteristics of the waste and the temperature to obtain maximum bio-oil. Moreover, inappropriate particle size will affect the production of pyrolysis oil.

Acknowledgment

The authors are grateful to the Education Fund Management Institution through the Merdeka Learning Campus Merdeka program for providing support during this project. Moreover, the authors are grateful to all parties who helped in the writing process of this study, especially the supervisor. Hopefully, this study can provide benefits for all and sundry

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