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Identification of Face Mask Waste Generation and Processing in Tourist Areas with Thermo-Chemical Process

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Keywords: waste management, COVID-19, mask

Abstract: The very high need for personal protective equipment (PPE) impacts the waste generated after using these tools. Therefore, to deal with mask waste during the COVID-19 pandemic, this study was carried out on the processing of mask waste using a thermal process and studied how the potential of this process was for the effectiveness of mask waste processing during the pandemic. This research was conducted on Honeymoon Beach by collecting data on mask waste generated during the pandemic, then measuring the waste proximate, ultimate, and calorific value and testing the thermal process using TGA and Piro GC-MS measurements. Most waste masks found on Honeymoon Beach are non-reusable masks, 94.74%, while reusable masks are 5.26%. The waste is then subjected to thermal processing and analysis using TGA and Piro GC-MS. Based on the data obtained, the thermal process can reduce the mass of non-reusable and reusable mask samples by 99.236% and 88.401%, respectively. The results of the Piro GC-MS analysis show that the lit mask waste will produce fragments of compounds that can be reused as fuel. The process is simple and easy and produces residues that can be reused to reduce environmental pollution due to waste generation during the COVID-19 pandemic.

Introduction

Coronavirus (SARS-CoV-2) is a new virus variant of SARS-CoV-1, first discovered in Wuhan City, China, at the end of 2019. This virus later became a COVID-19 pandemic (Corona Virus Disease 2019) in the early years of 2020 after its massive spread in various countries worldwide. The COVID-19 pandemic is a disease outbreak caused by the SARS-CoV-2 virus that attacks the respiratory system in humans. This virus can be easily transmitted from one human to another through droplets caused by coughing, sneezing, or breathing. The ease of transmission causes the virus to spread very quickly throughout the world. Therefore, to reduce and prevent coronavirus transmission, WHO (World Health Organization) provides policies and encourages all people worldwide to use masks in public places and places prone to being exposed to the virus. Masks are the most accessible and affordable

Personal Protective Equipment (PPE) to protect humans from the COVID-19 pandemic and can be easily used by all levels of society worldwide. The number of COVID-19 spreads has increased, causing the number of masks also to increase. For example, by February 2020, China had increased its medical mask production capacity by 14.8 billion due to the current high demand for masks (Selvaranjan et al. 2021). The study conducted by (Fadare and Okoffo, 2020) stated that the demand for masks in Japan had increased to more than 600 million masks as of April 2020. In developing countries, managing solid waste is more complicated than in developed countries due to limited recycling practices and solid waste management policies (Marshall and Farahbakhsh, 2013). The waste problem in Indonesia is a critical threat to the nation's economy, society, and environment. The country's massive waste production demands more space available for landfills, which competes with society's need for more sustainable locations (Fatimah

et al. 2020). During this pandemic, municipal solid waste management (MSW) has become one of the most challenging environmental problems (Septiariva et al. 2022, Sharma et al. 2020, Singh et al. 2022). Unsustainable waste management in many developing countries including Indonesia will increase vulnerability to the spread of the coronavirus through waste management practices. Improper collection practices can result in virus infection by municipal solid waste which can pose a risk of transmission (Singh et al. 2022). Health issues and medical waste have escalated during COVID-19 pandemic when it comes to managing MSW safely. Among many enormous negative effects of the COVID-19 outbreak, waste management activities are likely to receive more complaints over time. On the other hand, it was found that in Indonesia (Jakarta), the scale amount of medical waste reached 12,740 tons about 60 days after people were first infected with the corona virus in the area. Infectious waste is characterized as forgotten material containing pathogens (bacteria, viruses, parasites or fungi) in sufficient concentrations or quantities to cause disease in susceptible hosts (Sangkham, 2020).

The increase in the number of masks consumed has both a positive and a negative impact on the environment. The high consumption of masks causes the amount of mask waste to increase significantly. The mask waste is plastic, plastic particles, nylon, polystyrene, polycarbonate, etc. The use of medical masks in the UK every day for one year produces 124,000 tons of plastic waste (Ayse et al. 2020). Mask waste in Indonesia during 2020 also experienced a significant increase due to the increasing spike in the spread of COVID-19. The total mask waste produced per day by the Indonesian people was 1,345.99 to 2,018.98 tons (Sari et al. 2021). The environmental effects of the use of PPE have also been found on the coast in the City of Jakarta (Cordova et al. 2021) and

the Bali Island (Mutiara et al. 2021, Suryawan et al. 2021). Therefore, to reduce mask waste, it is necessary to have an effective and efficient waste treatment method to prevent the widespread impact of the waste.

Various methods have been developed and carried out to reduce mask waste that occurred during the COVID-19 pandemic. Mask waste management begins with pre-treatment, segregation, storage, transportation and processing, and final disposal stages. One method that is quite effective for processing mask waste is the thermal process. The thermal process is a process used to destroy mask waste at very high temperatures. This combustion process usually uses a temperature of 800–1200°C with a burning time of less than 25–35 minute (Trinh et al. 2020) to destroy all the mask material and leave the ash from the combustion. This method is considered the most effective and biologically safe because it can kill viruses left on masks and reduce the pile of mask waste in landfills. Therefore, in this study, we will study the potential of the thermal process for the processing of mask waste during the COVID-19 pandemic. This research hopes that mask waste can be managed optimally not to pollute the environment and not to cause various negative impacts on humans, animals, and plants.

Experimental

Data Collection and Location

This research was conducted in around Honeymoon Jimbaran Beach with an area of 0.3 ha. Data collection was carried out in January, 2021. This data collection was carried out during rainy conditions so that the observed waste was waste that had accumulated in an area. The collection of data on generation and composition is carried out by tracing along the coastline.

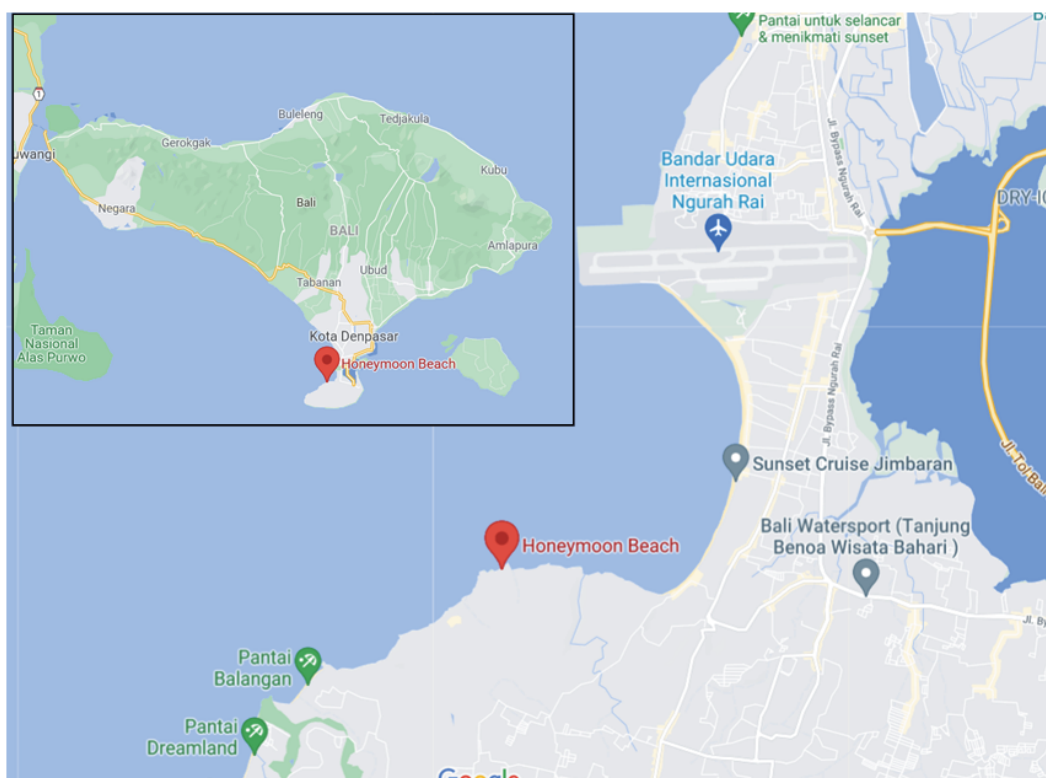


Fig. 1. Location of sampling of mask waste generation (Google Map, 2021)

Measurement of waste generation and design refers to the research by (Ammendolia et al. 2021). The waste collection method used in this activity is the line transect method. Garbage collection using the line transect method was carried out by spreading a transect measuring $10 \times 10 \text{ m}^2$. In a $10 \times 10 \text{ m}^2$ transect, every mask waste on the transect is taken. There were 5 transects in this study. The collected mask waste was then weighed using a portable electronic scale. Waste samples were obtained from the tourists. Equipment and supplies include scales, gloves, masks, and waste volume measuring devices. The sampling method is by determining the sampling location, preparing equipment, and collecting waste from each transect.

Material Characterization and Thermal Testing Analysis

Mask waste was collected and measured for Proximate, Ultimate, and Calorific Value using the ASTM method. The samples were then tested in the thermal process using TGA (Thermogravimetric analysis) measurements at a temperature of $0\text{--}800^\circ\text{C}$ with a heating rate of $10^\circ\text{C}/\text{min}$. To find out the components resulting from the thermal process, the mask waste was also tested using Piro GC-MS.

Results and Discussion

On average, the generation of PPE waste, including mask waste in the area around Honeymoon Jimbaran beach in the 1st to 3rd week, amounted to 0.00211 items per m^2 . Based on the graph in Figure 2, in the 1st week, the number of

PPE is $0.002 \text{ items}/\text{m}^2$ then there is an increase in the 2nd week by $0.0027 \text{ items}/\text{m}^2$ and a decrease in the 3rd week to $0.0017 \text{ items}/\text{m}^2$ (Fig. 2).

The expansion and decrease in the amount of PPE waste generated on Honeymoon Beach are influenced by the number of people visiting the destination and the COVID-19 situation in the location. It can be seen that the amount of PPE waste on Honeymoon Beach is relatively small compared to the amount of PPE in big cities such as Jakarta and other cities in various countries. Table 1 shows a comparison of the amount of PPE produced in multiple countries (Table 1). The amount of PPE waste found in Jakarta Bay is 0.13 tons per day. At the same time, in several cities in other countries such as Toronto (Canada), Bushehr's coastal areas (Iran) and Cox's Bazar Beach each have more waste than Honeymoon Beach, Indonesia, which is $0.00475 \text{ items}/\text{m}^2$, 350 items/day, and $0.00629 \text{ PPE}/\text{m}^2$. Honeymoon Beach has a relatively small amount of PPE waste because, during the COVID-19 pandemic, the number of tourists coming to the island has decreased drastically. Community activities are also minimal due to various rules for using health protocols.

Based on the research results on the generation of PPE waste, mainly mask debris found at Honeymoon Beach, Jimbaran, there are two types of masks: reusable masks such as cloth masks and non-reusable masks or medical masks. Figure 2 shows that non-reusable masks on Honeymoon Beach outweigh reusable masks, with a percentage of 94.74% for non-reusable and 5.26% for reusable. It does not concern only Honeymoon Beach, though. Based on research conducted

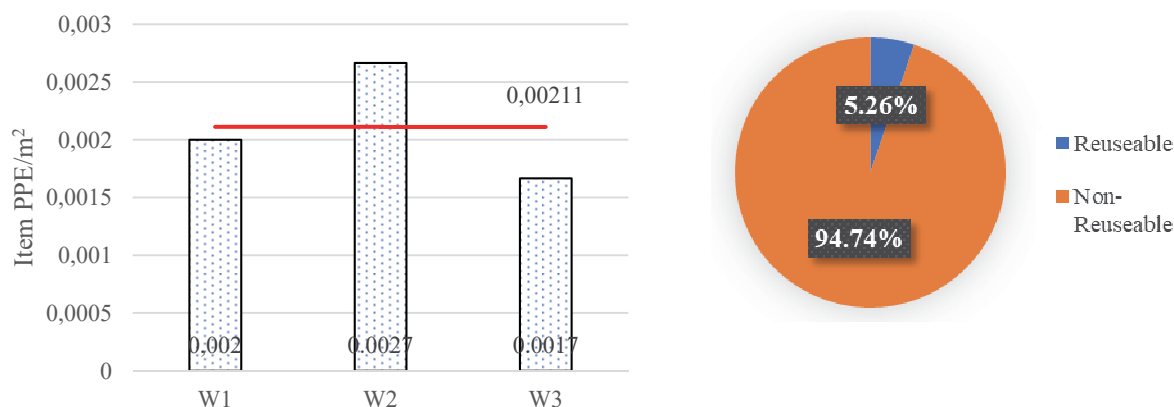


Fig. 2. PPE waste generation and composition of mask waste types at Honeymoon Beach

Table 1. Comparison of the amount of PPE waste in different countries

Location	Amount of PPE waste	Source
Toronto, Canada	$0.00475 \text{ items}/\text{m}^2$	(Ammendolia et al. 2021)
Jakarta Bay, Indonesia	$0.13 \pm 0.02 \text{ tons per day}$	(Cordova et al. 2021)
Africa	Twelve billion medical masks and cloth masks are thrown away every month.	(Benson et al. 2021)
Bushehr coastal area, Iran	350 items/day	(Akhbarizadeh et al. 2021)
Cox's Bazar Beach, Bangladesh	$6.29 \times 10^{-3} \text{ PPE}/\text{m}^2$	(Rakib et al. 2021)
Honeymoon Beach, Indonesia	$0.00211 \text{ items}/\text{m}^2$	This Research

in Toronto, Canada, the use of non-reusable masks also has a very high percentage compared to the use of reusable masks, namely 97% for non-reusable masks and 3% for reusable masks (Ammendolia et al. 2021). Many non-reusable masks are used for medical reasons and due to their effectiveness to dispel virus droplets compared to reusable masks. Non-reusable masks have various advantages to reduce the spread of the COVID-19 pandemic, including smaller pore sizes than cloth masks, making dust, bacteria, and viruses less likely to enter the human respiratory tract; non-reusable masks are also more hygienic and practical to use. Compared to other types of masks, besides that, this mask can be easily found in various places. However, the use of non-reusable masks can cause more waste than reusable masks, and this is because non-reusable masks can only be used once. Hence, they have a more significant potential to pollute the environment if not handled properly. Table 2 shows a comparison of the composition of PPE in different countries.

From the data collection and analysis of mask composition at Honeymoon Beach, a characterization test of reusable and non-reusable mask waste was carried out to determine the content contained in the two mask wastes. Based on the test results shown in Table 3, the water content in both types of masks is 0%; this indicates that both masks are dry and do not absorb moisture. On the other hand, reusable masks contain more dust than non-reusable masks. This is because reusable masks can be used repeatedly and make dust accumulate inside the mask. In addition, the larger pore size allows small dust particles to enter the pores of the mask. The study results stated that reusable masks have a pore size of around 100–461 m with a filtration efficiency of 63–84% (Neupane et al. 2019). For non-reusable masks, the average filtration efficiency is 97–100%. The dust content in reusable masks is 8.4%, while for non-reusable masks, it is 0%.

Meanwhile, for volatile content, non-reusable masks have a higher amount of content than reusable masks, which is 100% for non-reusable masks and 91.6% for reusable masks, respectively. The elements contained in the two types of masks are carbon, hydrogen, oxygen, nitrogen, and sulfur, which are the elements contained in dust and volatile substances. From the characterization test results, the total calorific value in reusable masks is 7562.67 kcal/kg, which is greater than that of non-reusable masks, which is 6352.86 kcal/kg. From the calculation of the calorific value, it can be concluded that both types of masks (reusable and non-reusable) have the potential to convert waste into high energy through proper mask waste treatment processes, one of which is through the thermal process. The test results on the ultimate parameter also

show that the elements with the highest percentage in the mask waste are the constituent elements of hydrocarbon compounds, namely the group of compounds that make up the fuel. Based on Table 3, carbon (C) has the highest percentage, 78.41% for reusable masks and 79.73% for non-reusable masks. Furthermore, for hydrogen (H) the percentage is 15.32% and 11.56% for reusable and non-reusable masks. The third highest element is oxygen (O), with a percentage of 6.12 and 8.18 for reusable and non-reusable masks-reusable.

TGA measurements were carried out on reusable and non-reusable mask waste. Based on the results of the TGA test in Figures 3 and 4, at a temperature of 100–300°C, there was a slight reduction in mass caused by degraded hydrocarbon compounds and volatile substances. Furthermore, a significant reduction in mass will occur at a temperature of 300–480°C, which indicates that the primary material that makes up the mask has been degraded. 300–480°C degradation has a slight difference in the amount of mass lost between reusable and non-reusable masks. In the reusable mask (Figure 3), the mass reduction begins at 350°C, then begins to experience a drastic decrease at 293°C and ends at 376°C with a mass reduction of 46.627%. Usually reusable masks use 3D printing (Swennen et al. 2020). Cellulose acetate is not flammable (Carter et al. 2020), the technical properties of cellulose acetate are determined by the degree of substitution which contributes to its solubility in a solvent and its application (Suryawan et al. 2022, Zahra et al. 2022).

In the case of non-reusable masks (Figure 4), the mass reduction started at 350°C and experienced a drastic decrease in mass starting at 439.16°C, then ending at 472.76°C with a percentage reduction in mass of 99.236%. In the thermal process, the residue produced by reusable mask waste is greater than that of non-reusable mask waste, 9.647% and -0.996%, respectively. The difference in the percentage reduction in mass, residue, and degradation temperature produced in reusable and non-reusable mask waste through a thermal process is due to the materials used in the two types of masks. Reusable masks generally use basic materials such as polyurethane (PU), natural fibers, polyester, and cotton. In general, these types of material can be degraded at a temperature of 200–500°C. Whereas, non-reusable or medical masks generally use polypropylene (PP) material with a degradation temperature range of 250–450°C. Typically, polyurethane, polyester, natural fiber, and cotton have a cyclic structure, while PP is generally a tertiary carbon type that forms a long polymer chain.

Materials with a cyclic chemical structure and chains with two bonds, in general, are more difficult to untie chains than non-cyclic materials, so more energy is needed to break the

Table 2. Comparison of types of PPE waste in different countries

Location	PPE Waste Generation	Source
Toronto, Canada	Disposable gloves (44%), 31% masks (97% non-reusable, 3% reusable), and disinfectant wipes (25%).	(Ammendolia et al. 2021)
Jakarta Bay, Indonesia	PPE (medical masks, gloves, protective clothing, face shields, raincoats) accounts for 15–16% of the total waste in rivers.	(Cordova et al. 2021)
Bushehr's coastal areas, Iran	10% PPE	(Akhbarizadeh et al. 2021)
Cox's Bazar beach, Bangladesh	Mask (97.9%)	(Rakib et al. 2021)
Honeymoon Beach, Indonesia	94.74% non-reusable PPE	This Research

chain (Miandad et al. 2019). Therefore, the final degradation temperature of reusable masks is slightly higher than that of non-reusable masks. In addition, the difference in structure is also the main reason for the difference in mass reduction and the percentage of residue that occurs in the two masks. The tertiary carbon chain structure in PP promotes carbocations during the degradation process through high temperatures. The entire tertiary carbon chain will be very quickly degraded (Jung et al. 2010). Materials with a cyclic structure and double chains or more (unsaturated bonds) make the bond-breaking process involve random chains and final chain cutting. It requires a longer degradation process compared to PP. As a result of the long degradation process, the thermal process on reusable mask waste resulted in a decrease in mass during the degradation process, which was smaller and produced a reasonably large residue compared to non-reusable mask waste. From the results of the TGA test, the use of a thermal process to degrade non-reusable mask waste is more effective when compared to the degradation of reusable waste.

Thermal process analysis was also carried out using the Piro GC-MS test to degrade mask waste, especially non-reusable mask waste, as the highest percentage of plastic waste

in Honeymoon Beach. Pyrolysis GC-MS (Pyrolysis GC-MS) is a test method to characterize a polymer or composite material. In the test using Pyro GC-MS, polymer materials were broken down into several smaller fragments or compounds. Figure 5 shows the results of the Piro GC-MS test for non-reusable medical mask waste with three layers of filter made of PP as the primary material. Based on the graph, the PP material contained in the non-reusable mask waste is divided into 30 small fragments. Each of these peaks has a different retention time and intensity, which shows different concentrations and differences in the compounds produced. Based on the analysis results, the pyrolysis process on PP polymer has various types of aliphatic compounds and several aromatic compounds. Some of the compounds with the highest concentration included 1-decycloxy-2-nitrobenzene, which was found at a retention time of 20.517 minutes with a concentration of 9.87%, 2-azido-17-(1.5 dimethyl-hexyl)-10-13-dimethyl-hexadecahydro at retention time 19.967 minutes with a concentration of 7.17%, Eicosane compound, 3-cyclohexyl-(3-cyclohexyleicosane) at a retention time of 42.705 minutes with a concentration of 6.41%, ammonium carbamate (5.53%), 9-octadecenoic acid (5 .09%), cyclopentane (4.74%) and

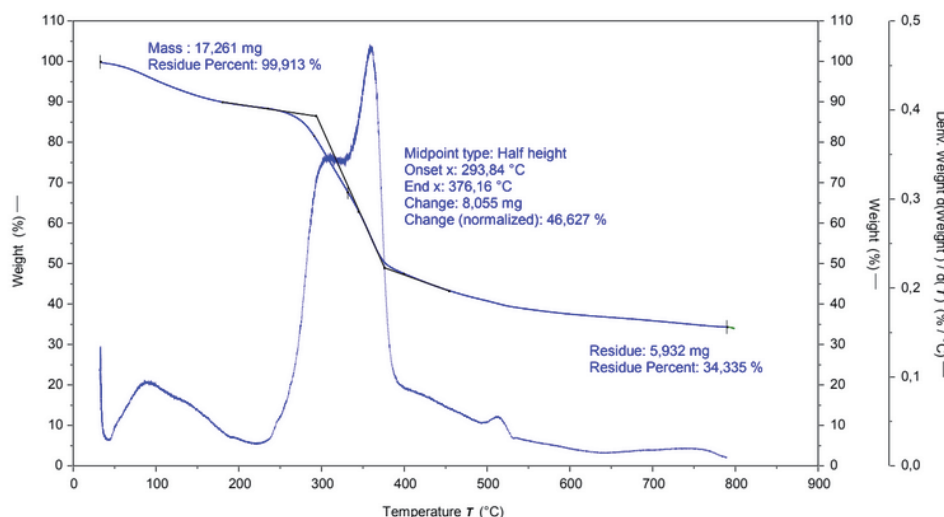


Fig. 3. TGA test results for cloth mask waste (Reusable)

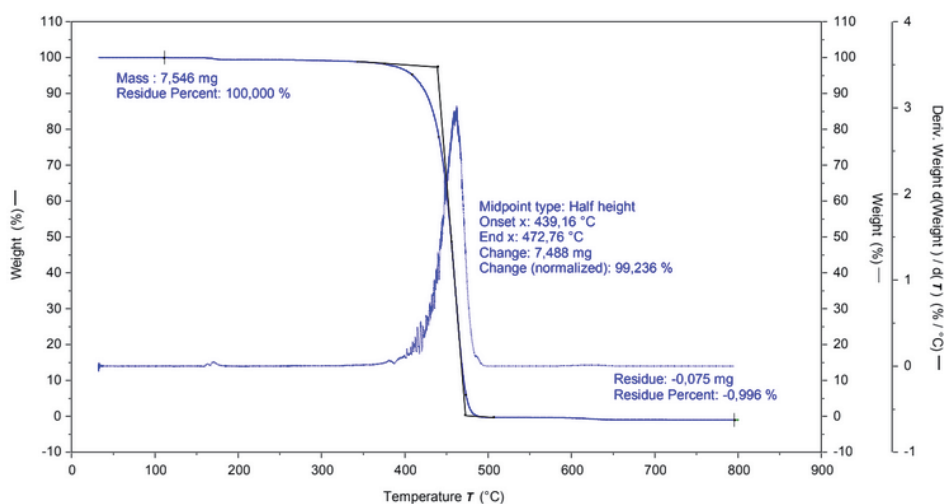


Fig. 4. TGA test results for 3-layer (non-Reusable) medical mask waste

other compounds (Figure 5). The compounds resulting from the pyrolysis of the mask waste are generally hydrocarbon compounds with long chains in the form of liquids that allow them to be reused as fuel if appropriately processed.

Conclusions

The mask waste found at Honeymoon Beach has a generation density of 0.00211 items/m². This amount is small compared to the amount of waste in Jakarta Bay and several countries globally. In general, 94.74% of mask waste is non-reusable mask waste, while 5.26% is reusable mask waste. By going through a thermal process at temperatures up to 800°C, the mask waste can be degraded and broken down into several components that can be reused. Based on the results of the TGA analysis, it is known that at a temperature of 350–472.76°C, non-reusable mask waste can be degraded and it experienced a decrease in mass of 99.236% with a total residue of -0.996%.

In contrast, for reusable mask waste at a temperature of 350–474.32°C for thermal degradation process. The results of the thermal process were analyzed using Piro GC-MS for non-

-reusable mask waste. They obtained 30 fragments of compounds resulting from the breakdown of PP polymer, which is the primary material for the non-reusable masks. These compounds consist of aliphatic compounds, namely hydrocarbons with long chains and some aromatic compounds. The compounds resulting from the breakdown of these polymers are generally reusable and have potential as fuels. From different research results, it can be concluded that the thermal process has a very high potential to be used as a method of processing non-reusable and reusable mask waste. This process has various advantages, including leaving minimal residue, the process is carried out quickly, biologically safer, and the resulting residue can be reused into something useful.

Acknowledgement

This research was implemented and fully supported by the Japan Society for The Promotion Science and Indonesia Directorate General of Research, Technology and Higher Education (JSPS/DG-RSTHE), through a Bilateral Joint

Table 3. The results of the characterization of reusable and non-reusable mask waste

Parameters	Unit	Reusable	Non-Reusable
Proximate			
Water Content	%	0	0
Ash Content	%	8.4	0
Fix Carbon	%	0	0
Volatile Content	%	91.6	100
Ultimate			
Carbon (C)	%	78.41	79.73
Hydrogen (H)	%	15.32	11.56
Oxygen (O)	%	6.12	8.18
Nitrogen (N)	%	0.14	0.21
Sulphur (S)	%	0.01	0.32
Caloric Value	kcal/kg	7562.67	6352.86

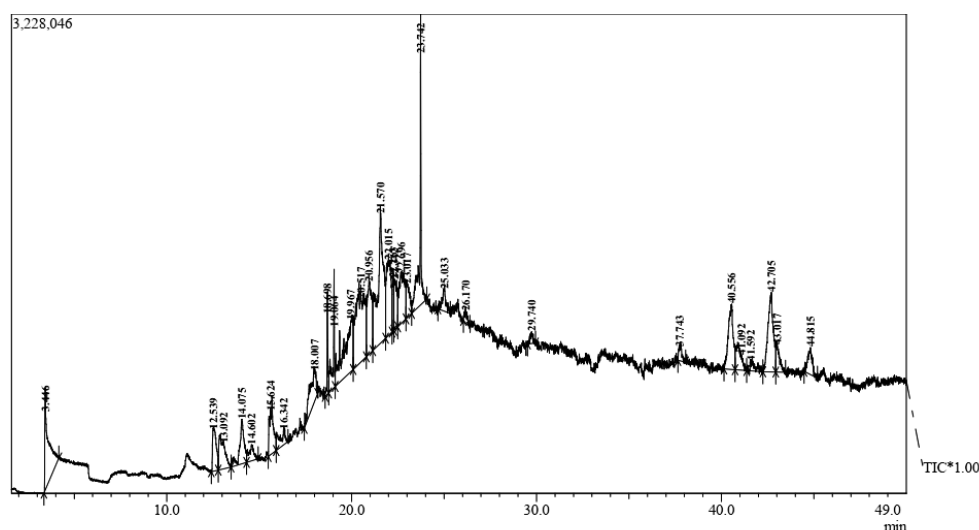


Fig. 5. Piro GC-MS test results for 3-layer (non-Reusable) medical mask waste

Research Projects 2019–2022 between Universitas Pertamina, Indonesia and Toyohashi University of Technology, Japan.

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