Treatment of Electrical and Electronic Waste to Reduce Environmental Issue

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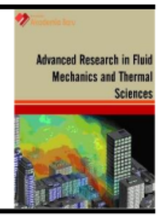

Treatment of Electrical and Electronic Waste to Reduce Environmental Issue

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ABSTRACT

Electrical and electronic wastes (e-waste) are harmful to the environment and human life due to it contain non degradable and hazardous components. Treatment of e-waste is important in order to reduce the environmental issues. Conversion of e-waste into valuable products including liquid oil is believed as one of the good ways to solve the problem. For this purpose, application of microwave technology for e-waste pyrolysis and liquid oil product distillation is very interesting because of the rapid heating processes of materials. This study reported on e-waste processing techniques and specifically highlights the use of microwave technology to convert laptop computer case into liquid oil. The treatment of laptop computer case in this work included microwave pyrolysis of the sample and microwave distillation of the liquid oil product. The result showed that the average yield of liquid oil from pyrolysis of laptop computer case was about 37 % by mass. After liquid oil distillation process, the average yields of each fuels fraction were 67.6 vol.% gasoline, 42.1 vol.% kerosene, 42.8 vol.% diesel, and 14.1 vol.% heavy fuel and residue.

Keywords:
E-waste; microwave pyrolysis; microwave distillation; liquid oil; environmental issue

1. Introduction

At present, it cannot be denied that the high production capacity of electrical and electronic equipment in the world is not only caused by the shorter duration of use of the products but also due to high socio-economic growth including in Indonesia. Indonesia is one of the largest consumers of electronic equipment, in which there were around 435.19 million mobile phone users in 2017 [1]. Moreover, household's computer ownership increases continuously from year to year. BPS-Statistics Indonesia reported that the percentage of household that own computers rose from 12.32 percent in 2011 to 19.11 percent in 2017 [1]. These data provide an overview of the amount of electrical and

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electronic waste (e-waste) that could be generated over time. Study by Kumar *et al.,* [2] evinced that gross domestic product (GDP) has a linear relationship with the amount of e-waste generated.

In Asia, around 18.2 million tons by 2016 of the e-waste was generated whereas in the European continent, including Russia, generated an amount of e-waste of 12.3 million tons [3]. Globally, the amount of e-waste by 2016 was 44.7 million tons and is projected to grow to 49.8 million tons by 2018 [3]. This condition indicates that the high amount of e-waste not only generates in developed countries but also in developing countries including Indonesia.

E-waste is often processed in the informal sector, and many e-waste disposals are unsafe and not protected by formal regulation. Inadequate treatment of e-waste that do not utilize adequate means, facilities, and trained people poses serious health issues since it contains hazardous components (heavy metals and inorganic acids), including contaminating air, water, and soil, crops, drinking water, fish, livestock and putting people's health at risk [3-5]. A previous study reported that plastics from e-waste generally contain toxic and fire-resistant halogens components such as polybrominated dibenzo dioxins/furans that can cause a serious environmental problem in e-waste recycling sites [6]. An actual case of environmental violation caused by informal business activities in Indonesia is the heavy metal contamination case in Ciampea-Bogor, Munjul-East Jakarta, Bogor, Tangerang, and Tegal that caused mental disorders of toddlers, as well as paralysis and death [7-10].

The negative impacts arising from hazardous wastes including electronic waste have encouraged the United Nations and all Member States to adopt the 2030 Agenda for Sustainable Development in 2015. In this agenda, management or treatment of e-waste is closely related to Goal 3 (Good health and Well-being), Goal 6 (Clean water and Sanitation), Goal 11 (Sustainable Cities and Communities), Goal 12 (Responsible Consumption and Production), and Goal 14 (Life Below Water) [3]. In general, these goals aim to reduce waste generation through prevention, reduction, repair, recycling, and reuse that can reduce pollution, eliminate dumping, and minimize release of hazardous chemicals and materials in order to minimize their adverse impacts on human health and the environment. It is therefore necessary for countries to formalize the environmentally sound management of e-waste treatment, as also suggested by [11,12]. Unfortunately, until now there are no applicable laws and regulations in Indonesia that specifically define e-waste, where e-waste is still part of hazardous waste [13].

Based on the facts above, the alternative processing of e-waste into useful products remarkably needs to be done. It is known that e-waste contains a number of hydrocarbons materials such as plastics and rubber. It can be processed into other valuable products of chars, oils, and gases [14, 15]. Plastics from e-waste can be converted into liquid oil and solid carbon through pyrolysis process by using electrical furnace or microwave reactor [15-19]. Microwave-assisted pyrolysis has been also implemented for treating the e-waste [19]. The rapid heating process of materials using this technology can overcome the limitations of conventional technology leading to improvement of products yield. It has been reported in a recent study that pyrolysis temperature and type of e-waste affect yield of liquid oil in which good yield of products was found at microwave pyrolysis temperature of 450°C [19].

This paper reported on the processing techniques of e-waste for environmentally friendly management of e-waste. Thermal conversion processes using microwave technology including microwave pyrolysis and microwave distillation to convert e-waste into valuable liquid products are particular way reported in this work. Therefore, this research is objected to investigate liquid fuels production from laptop computer case waste through pyrolysis and distillation processes under microwave irradiation.

2. Materials and Methods

2.1 Materials

E-waste from laptop computer case was used in this work. It was collected from several local landfills in Semarang, Indonesia. After separated from the metal components, the plastic parts of the e-waste were then shredded into small pieces with an average size of about 0.5-2 cm^2. Commercial activated carbon powder was also used as an absorber material to absorb and convert microwave energy into heat. Nitrogen gas with 99.99% purity was used to ensure inert environment and to sweep the vapor product into the condenser.

2.2 Experimental Apparatus

Figure 1 shows the schematic representation of the pyrolysis experimental setup. It consists of three main units: microwave reactor, cooler, and controller units. Detailed descriptions can be obtained in a previous study [19].

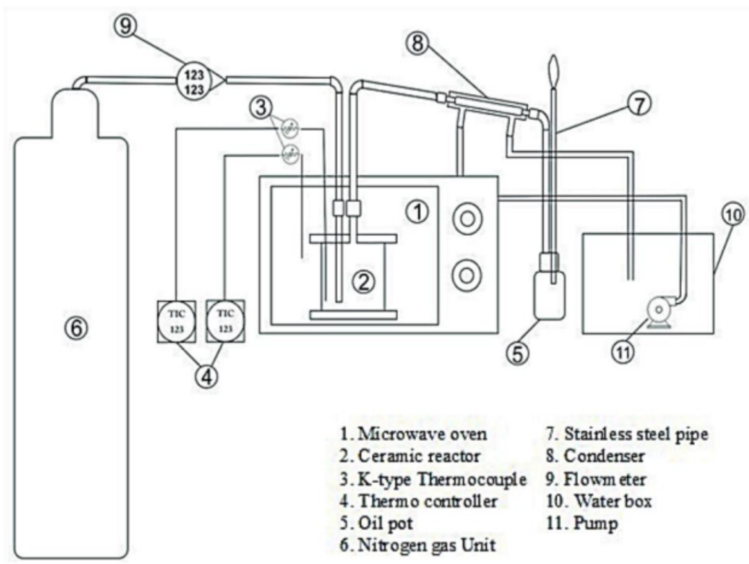

Fig. 1. Schematic diagram of pyrolysis experimental apparatus

The schematic diagram of the distillation experimental setup is presented in Figure 2. It also mainly consists of microwave reactor, cooler, and controller units. Microwave reactor includes a modified microwave oven and a Pyrex reactor. The modified microwave oven has a frequency of 2.45 GHz and a maximum output power of 0.9 kW. The Pyrex reactor of 1000 ml contains a K-type thermocouple at the center of the reactor and activated carbon. Cooler unit consists of a double pipe glass condenser, a liquid collector of 500 ml glass bottle, a water bath and a pump for cool water circulation.

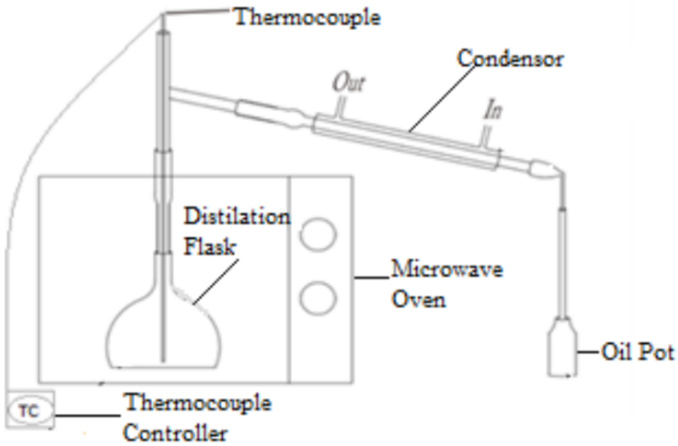

Fig. 2. Schematic diagram of distillation experimental apparatus

2.3 Pyrolysis Experiments

Pyrolysis processes were carried out at a temperature of 450°C based on the optimum condition reported in the previous study [19]. The amount of laptop computer case waste and activated carbon in the reactor was kept constant at 150 g and 75 g, respectively. During each experiment, pure nitrogen gas was supplied at 0.3 l/min to ensure inert environment within the reactor and other equipment. The flowed nitrogen gas was also used to sweep the pyrolysis vapor product from the reactor into the condenser and oil collector.

After each pyrolysis experiment, the amount of liquid oil was weighed to obtain the yields. Three samples were taken to obtain the average. The liquid oil was then subjected for analyzing the oil compounds using a Gas Chromatography–Mass Spectrometry (GC–MS) analyzer combined with NIST MS 2.0 software.

2.4 Distillation Experiments

The liquid oils produced from microwave pyrolysis of laptop computer case waste were then processed through standard single stage distillation to separate fuels fraction. Separation of the fuel fraction was carried out based on the boiling temperature range of each hydrocarbon components which is 30-210°C for gasoline and naphtha fractions, 150-275°C for kerosene and paraffin fractions, 170-360°C for diesel oil fractions, and the rest are heavy fuels and residues fractions. Three samples were taken to obtain the average.

3. Results and Discussion

3.1 E-Waste Pyrolysis

Plastics material samples from laptop computer case that were separated from the metal parts were used in this study. Plastic is the result of polymerization that is a combination of monomers to form long chains. It was reported that laptop computer case samples contain high amount of carbon and hydrogen elements, and such amount of nitrogen, indicated that the samples are composed of polymeric materials that a combination of polycarbonate and Acrylonitrile Butadiene Styrene (ABS)

[15,19]. Plastic from laptop computer case has a high potential to be converted into liquid oil and gas fuels as it contains more than 97% volatile matter.

Figure 3 shows the average yield of products from microwave pyrolysis of laptop computer case at a temperature of 450°C. As shown in the figure, high yield of liquid oil product of about 37 wt.% was obtained, although still below yield of solid product of about 42 wt.%. This tendency of product yields is also observed in previous studies [15,19]. The liquid oils obtained in the pyrolysis process were a complex mixture of hydrocarbon compounds. Study by Hall and William [20] reported that the largest component of the liquid oil produced from mixed WEEE plastic was phenol, 4-isopropylphenol and styrene. The high concentration of phenol and phenol derivatives in liquid oil might be came from polycarbonate and ABS as the main constituents of laptop computer case [15, 19]. Figure 3 also indicates that laptop computer case pyrolysis generated high amount of solid or char and gas products. It is expected that the char product contains more quantities of metals such as magnesium, copper, aluminium, silicon, calcium, titanium, and zinc, as well as carbon and oxygen [15,20] that could be utilized as catalysts, pigment component, or fertilizer. In the meantime, the gas product generally composes of light hydrocarbons (C_1–C_5) together with large amount of CO_2 and CO due to the presence of oxygen in the plastic component of the waste [15,20].

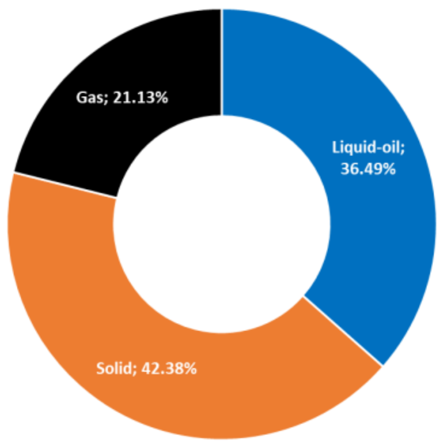

Fig. 3. Yield of products from microwave pyrolysis of laptop computer case at 450°C

3.2 Pyrolytic Oil Composition

A Gas Chromatography–Mass Spectrometry (GC-MS) was employed to analyze the chemical compounds contained within the liquid oil. Different substances in a liquid sample could be identified by this device because it is a combination of gas-liquid chromatography and mass spectrometry analysis methods. The aim is to separate chemical elements in certain compounds and identify their molecular levels by heating the liquid samples.

Figure 4 shows the GC-MS chromatogram of the liquid oil produced from microwave pyrolysis of laptop computer case at 450°C. The characteristic peaks identification were done by applying NIST MS 2.0 library software on their spectra. It can be observed from the figure that there are 29 peaks compounds identified. Among them, seven main peaks were obtained at retention time of 7.02 min, 8.18 min, 10.91 min, 12.50 min, 19.44 min, 40.46 min, and 44.77 min. The molecular compounds identified in this liquid oil are also listed in Table 1 in order to obtain an idea about the oils composition.

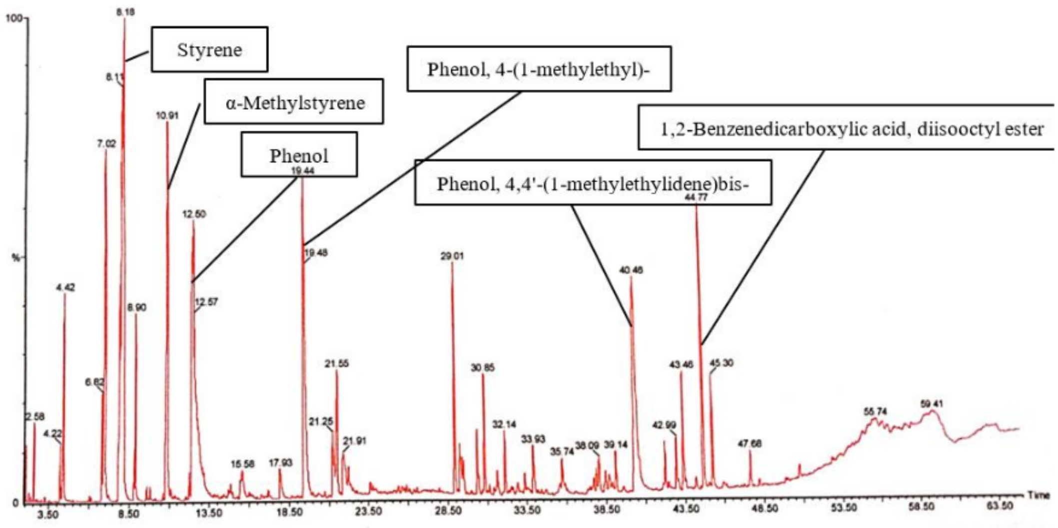

Fig. 4. Liquid oil chromatogram from microwave pyrolysis of laptop computer case at 450°C

Table 1
Liquid oil composition from pyrolysis of laptop computer case at 450°C

RT (min)	Compound	% Area
4.419	Toluene (C_7H_8)	2.7
7.02	Ethylbenzene (C_8H_{10})	6.7
8.176	Styrene (C_8H_8)	19.3
8.896	Benzene, (1-methylethyl)- (C_9H_{12})	1,5
10.907	α-Methylstyrene (C_9H_{10})	8.2
12.503	Phenol (C_6H_6O)	15.2
15.584	Phenol, 2,6-dymethyl- ($C_8H_{10}O$)	1.2
17.935	Phenol, 4-ethyl- ($C_8H_{10}O$)	0.9
19.435	Phenol, 4-(1-methylethyl)- ($C_9H_{12}O$)	8.8
21.246	Phenol, p-tert-butyl- ($C_{10}H_{14}O$)	0.9
21.551	Benzenebutanenitrile ($C_{10}H_{11}N$)	2.6
21.911	p-Isopropenylphenol ($C_9H_{10}O$)	1.4
29.009	Benzene, 1,1'-(1,3-propanediyl)bis- ($C_{15}H_{16}$)	3.6
29.294	Phenol, 4-(1-methyl-1-phenylethyl)- ($C_{15}H_{16}O$)	0.9
30.395	Naphthalene, 1,2,3,4-tetrahydro-1-phenyl ($C_{16}H_{16}$)	0.9
30.85	3,5,3',5'-Tetramethylbiphenyl ($C_{16}H_{18}$)	1.6
31.64	Benzene, 1,1'-(3-methyl-1propene-1,3diyl)bis- ($C_{16}H_{16}$)	0.5
32.135	Benzene, 1,1'-(3-methyl-1propene-1,3diyl)bis- ($C_{16}H_{16}$)	1.0
33.926	Phenol, 4-(1-methyl-1-phenylethyl)- ($C_{15}H_{16}O$)	0.9
35.742	2-Phenylnaphthalene ($C_{16}H_{12}$)	0.8
38.088	9-Phenyl-5H-benzocycloheptene ($C_{17}H_{14}$)	0.6
39.143	Tetracyclo[5.2.1.0(2,6).0(3,5)]non-8-ene, 4-methyl-4-phenyl-, exo- ($C_{17}H_{18}$)	0.7
40.459	Phenol, 4,4'-(1-methylethylidene)bis- ($C_{15}H_{16}O_2$)	9.4
42.274	1-Propene, 3-(2-cyclopentenyl)-2-methyl-1, 1-diphenyl- ($C_{21}H_{22}$)	0.6
42.99	Triphenyl phosphate ($C_{18}H_{15}O_4P$)	0.7
43.46	(2,3-Diphenylcyclopropyl)methyl phenyl sulfoxide, trans- ($C_{22}H_{20}S$)	1.6
44.77	1,2-Benzenedicarboxylic acid, diisooctyl ester ($C_{24}H_{38}$)	5.0
45.296	1-Propene, 3-(2-cyclopentenyl)-2-methyl-1, 1-diphenyl- ($C_{21}H_{22}$)	1.6
47.676	Terephthalic acid, di(2-ethylhexyl) ester ($C_{24}H_{38}O_4$)	0.6

As it is observed from Table 1, oils composition is predominantly composed of ethylbenzene, styrene, phenol and phenol derivatives. The general liquid oil product components based on carbon atom number can also be seen in Table 1. The laptop computer case pyrolysis oils are complex mixtures of hydrocarbon compounds. The compound components have been obtained from C_7 to C_{24} structures. It indicates that the liquid oils are mainly composed of lighter hydrocarbon components. This indicates that a great amount of liquid oil has the characteristics of gasoline, kerosene, and diesel fuels with carbon atom structures of C_4 to C_{12}, C_{10} to C_{16}, and C_{12} to C_{20}, respectively.

3.3 Pyrolytic Oil Distillation

The liquid oils produced from previous pyrolysis process of laptop computer case waste were then processed through distillation to obtain the fuel fractions. The distillation process was carried out by using a microwave assisted distillation reactor. The result of the distillation process is shown in Figure 5.

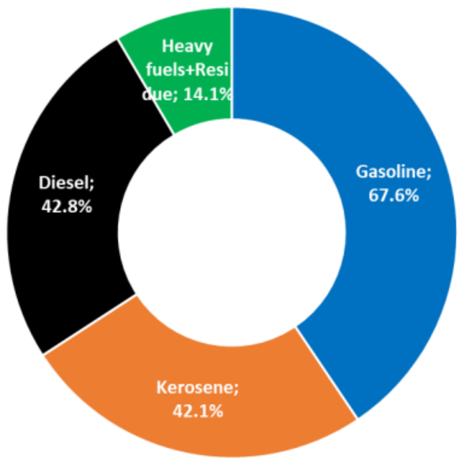

Fig. 5. Average yields of fuel fractions from microwave-assisted distillation of liquid oil

The result of the distillation showed that there were 507 ml of gasoline fraction, 316 ml of kerosene fraction, 321 ml of diesel fraction, and 106 ml of heavy fuel and residue fractions. The results indicated that gasoline fraction was the highest fuel fraction in liquid oil while the lowest was heavy fuel and residue fraction. Based on percentage of the yields, the average fraction of gasoline was 67.6 vol.%, kerosene was 42.1 vol.%, diesel was 42.8 vol.%, and heavy fuel and residue was 14.1 vol.%. The yield of the fuel fractions is consistent with the results of the liquid oil composition (except for heavy fuels and residues) where the liquid oil content is more dominated by styrene, phenol, and phenol derivatives with an area of 19.3%, 15.2%, and 24.4%, respectively. Phenol is a hydrocarbon compound which is classified as kerosene fraction while styrene is classified as gasoline fraction.

4. Conclusions

Plastics from laptop computer case were successfully pyrolyzed and distilled by using microwave reactors to produce liquid fuels. The average yields of products from microwave pyrolysis of the samples at 450°C were about 37 wt.% liquid oil products, 21 wt.% gas products, and about 42 wt.% solid products. The relatively high liquid oil product illustrates that laptop computer case waste has the potential as source of hydrocarbon fuels. This is evidenced by the results of GC-MS analysis where the liquid oils are mainly composed of lighter hydrocarbon components with carbon atom structures of C_6 to C_{24}. The liquid oil distillation process using microwave reactor showed that more than 80 vol.% of the products were light hydrocarbon fuels consisting of about 68 vol.% gasoline fraction, 42 vol.% kerosene fraction, and 43 vol.% diesel fractions. These results indicated that the use of microwave technology is very promising for converting e-waste into liquid oil in order to reduce environmental issues. However, further studies are needed to improve the quality of each fuel fraction so that it can be used for internal combustion engine applications.

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References
[1] BPS-Statistics-Indonesia. Telecommunication Statistics in Indonesia 2017. Sub-directorate of Communications and Information Technology, BPS-Statistics Indonesia (2017).
[2] Kumar, Amit, Maria Holuszko, and Denise Crocce Romano Espinosa. "E-waste: an overview on generation, collection, legislation and recycling practices." *Resources, Conservation and Recycling* 122 (2017): 32-42. https://doi.org/10.1016/j.resconrec.2017.01.018
[3] Baldé, C. P., V. Forti, V. Gray, R. Kuehr, and P. Stegmann. "The Global E-Waste Monitor–2017. Bonn/Geneva/Vienna: United Nations University (UNU), International Telecommunication Union (ITU)." *International Solid Waste Association (ISWA)* (2017).
[4] Ma, Jing, Kurunthachalam Kannan, Jinping Cheng, Yuichi Horii, Qian Wu, and Wenhua Wang. "Concentrations, profiles, and estimated human exposures for polychlorinated dibenzo-p-dioxins and dibenzofurans from electronic waste recycling facilities and a chemical industrial complex in Eastern China." *Environmental science & technology* 42, no. 22 (2008): 8252-8259. https://doi.org/10.1021/es8017573
[5] Heacock, Michelle, Carol Bain Kelly, Kwadwo Ansong Asante, Linda S. Birnbaum, Åke Lennart Bergman, Marie-Noel Bruné, Irena Buka et al. "E-waste and harm to vulnerable populations: a growing global problem." *Environmental health perspectives* 124, no. 5 (2016): 550-555. https://doi.org/10.1289/ehp.1509699
[6] Tue, Nguyen Minh, Agus Sudaryanto, Tu Binh Minh, Tomohiko Isobe, Shin Takahashi, Pham Hung Viet, and Shinsuke Tanabe. "Accumulation of polychlorinated biphenyls and brominated flame retardants in breast milk from women living in Vietnamese e-waste recycling sites." *Science of the Total Environment* 408, no. 9 (2010): 2155-2162. https://doi.org/10.1016/j.scitotenv.2010.01.012
[7] Maheswari, Hesti, Gatot Yudoko, and Akbar Adhiutama. "Government and intermediary business engagement for controlling electronic waste in Indonesia: a sustainable reverse logistics theory through customer value chain analysis." *Sustainability* 11, no. 3 (2019): 732. https://doi.org/10.3390/su11030732
[8] Safrudin, A., and A. Sitorus. "E-waste Separate, Discharge and Collection." In *Regional Technical Training Workshop on Environmentally Sound Collection, Separation and Managementof E-wastes, Ministry of Environmental of Indonesia-Secretariat of the Basel Convention-Basel Convention Regional Centre for South–East Asia, Jkarta*, pp. 13-15. 2010.
[9] Safrudin, A. and A. Sitorus. In the Red Zone Survival, Lead Exosure, and Its Impact of ULAB Recycling in Jakarta. Blacksmith Institute (2010).
[10] Wahyono, Sri. "Kebijakan Pengelolaan Limbah Elektronik Dalam Lingkup Global Dan Lokal= Electronic Waste Management Policies in the Scope of Global and Local." *Jurnal Teknologi Lingkungan* 14, no. 1 (2013): 49-58. https://doi.org/10.29122/jtl.v14i1.1437
[11] Norazli, O., M. Roslina, A. B. Noor Ezlin, and M. Y. Muhd Noor. "Developing an integrated electronic waste management approach in Malaysia." *Journal of Advanced Research in Business and Management Studies* 1, no. 1 (2015): 5-13.

[12] Beleya, Prashanth, Cheah Xin Ci, and Chua Ling Wen. "Challenges in Enhancing Solid Waste Management towards Sustainable Environment: Local Council Perspectives." *Journal of Advanced Research in Business and Management Studies* 16, no. 1 (2019): 44-59.

[13] Damanhuri, E. "Country chapter." *State of the 3Rs in Asia and the Pacific. United Nations center for Regional Development, Nagoya* (2017).

[14] Quan, Cui, Aimin Li, and Ningbo Gao. "Combustion and pyrolysis of electronic waste: thermogravimetric analysis and kinetic model." *Procedia Environmental Sciences* 18 (2013): 776-782. https://doi.org/10.1016/j.proenv.2013.04.104

[15] De Marco, I., B. M. Caballero, M. J. Chomón, M. F. Laresgoiti, A. Torres, G. Fernández, and S. Arnaiz. "Pyrolysis of electrical and electronic wastes." *Journal of Analytical and Applied Pyrolysis* 82, no. 2 (2008): 179-183. https://doi.org/10.1016/j.jaap.2008.03.011

[16] Martinho, Graça, Ana Pires, Luanha Saraiva, and Rita Ribeiro. "Composition of plastics from waste electrical and electronic equipment (WEEE) by direct sampling." *Waste Management* 32, no. 6 (2012): 1213-1217. https://doi.org/10.1016/j.wasman.2012.02.010

[17] Moltó, Julia, Rafael Font, Araceli Gálvez, and Juan A. Conesa. "Pyrolysis and combustion of electronic wastes." *Journal of Analytical and Applied Pyrolysis* 84, no. 1 (2009): 68-78. https://doi.org/10.1016/j.jaap.2008.10.023

[18] Sun, Jing, Wenlong Wang, Zhen Liu, and Chunyuan Ma. "Recycling of waste printed circuit boards by microwave-induced pyrolysis and featured mechanical processing." *Industrial & engineering chemistry research* 50, no. 20 (2011): 11763-11769. https://doi.org/10.1021/ie2013407

[19] Anis, Samsudin, and Suprayoga Edi Lestari. "Production of Liquid Oil from Thermolysis of Electrical and Electronic Wastes (E-waste) under Microwave Irradiation." *Journal of Physical Science* 29 (2018): 53-62. https://doi.org/10.21315/jps2018.29.s2.5

[20] Hall, William J., and Paul T. Williams. "Analysis of products from the pyrolysis of plastics recovered from the commercial scale recycling of waste electrical and electronic equipment." *Journal of Analytical and Applied Pyrolysis* 79, no. 1-2 (2007): 375-386. https://doi.org/10.1016/j.jaap.2006.10.006

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