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Comparison of Plastic Waste Processing Machine Models in The Producing of Plastic Grains and Oil Fuel and Its Cost Analysis

Perbandingan Model Mesin Pengolah Sampah Plastik dalam Produksi Butir Plastik dan Bahan Bakar Minyak serta Analisis Biayanya

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ABSTRAK

Alat pengolah sampah plastik melalui proses pemanasan dan destilasi dapat menghasilkan butir plastik dan bahan bakar minyak sebagai alternatif solusi lain untuk masalah sampah plastik. Pengujian kinerja dari 3 (tiga) buah model mesin pengolah sampah plastik (model I, II, and III) yang masing-masing dilengkapi dengan satu, dua, dan tiga tabung distilasi, dilakukan untuk membandingkan hasil produksi butir plastik dan bahan bakar minyak yang dapat dihasilkan. Selanjutnya, biaya ekonomiannya dianalisis menggunakan besaran nilai titik impas (break even point). Hasil pengujian menunjukkan bahwa Model I menghasilkan butir plastik tertinggi, yaitu sebesar 2,76 kg dan Model III menghasilkan bahan bakar minyak tertinggi, yaitu sebesar 51 mL. Hasil uji statistik diperoleh bahwa tidak ada perbedaan yang signifikan antara Model I, II, dan III terhadap kuantitas butir plastik dan bahan bakar minyak dengan hasil ($p>\alpha$; (1,000 > 0,05). Hasil analisis keekonomian menunjukkan bahwa titik impas (break even point) dari masing-masing model (I, II dan III) akan tercapai dalam waktu 44,47 dan 35 hari dengan waktu operasi selama 8 jam per hari dan 10,5 kg/hari sampah plastik. Secara ekonomi, model III menunjukkan pengembalian investasi yang relatif lebih cepat dibandingkan model I dan II. Hasil penelitian ini bermanfaat bagi pengembangan perancangan mesin pengolah sampah plastik untuk skala yang lebih besar di industri. Selain itu, diharapkan juga dapat memberikan nilai tambah ekonomi masyarakat dan alternatif solusi bagi permasalahan sampah plastik di Indonesia.

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ABSTRACT

A plastic waste processing apparatus, employing heating and distillation processes can yield plastic grains and oil fuel, providing an alternative solution to the plastic waste problem. Performance tests were conducted on 3 (three) models of plastic waste processing machines (Models I, II, and III) equipped with one, two, and three distillation cylinders, respectively, to compare the quantity of plastic grains and oil fuel produced. Furthermore, an economic cost analysis was also conducted by using the break even point as a metric. The results showed that Model I yielded the highest quantity of plastic grains (2.76 kg), and Model III produced the highest amount of oil fuel (51 mL). Statistical tests indicated no significant differences ($p>\alpha$; 1.000 > 0.05) among Models I, II, and III concerning the quantities of plastic pellets and oil fuel. Economic analysis demonstrated that the break-even points for each model (I, II, and III) would be attained in 44, 47, and 35 days, respectively, assuming an 8-hour daily operation and processing 10.5 kg/day of plastic waste. Model III economically showed a relatively more cost-effective compared to Models I and II. The findings of this research can be applied to the development of mass-production of plastic grains and oil fuel from plastic waste on an industrial scale. This research could be contributed to the increas in community economic value and offer an alternative solution to the plastic waste issue in Indonesia.

1. INTRODUCTION

1.1 Background

Plastic waste presents a hazardous environmental concern due to its resistance to decomposition. This material is subjected to a continued degradation process when introduced into the soil, with certain varieties necessitating up to a century to break down fully. Meanwhile, the high resistance to decomposition by microorganisms results in the gradual depletion of organic and inorganic minerals over time. This depletion has adverse consequences on local fauna, including earthworms and other microorganisms, affecting their ability to locate food and suitable shelter in affected areas (Evania, 2021). The use of plastic pollutes the soil, groundwater, and subterranean organisms. The released toxins can infiltrate and affect the organisms responsible for decomposition. Furthermore, plastic waste disrupts water channels absorbed by the soil and decreases fertility by affecting air circulation (Lestari et al., 2019).

The local community manages Sembada Waste Bank, and its customers are also residents of the Jetis, Donokerto, and Turi villages in Sleman. As a result of the classification at the bank, only residual waste is expected to be sent to the Piyungan landfill. In the bank, Household waste is classified based on its type for processing until utility value is reported. At the recycling center, residents are introduced to the principles of 3R (reduce, reuse, recycle) (Sari, 2018). The community also exchanges their waste for money, which can be used for other types of waste.

Processing plastic waste using a machine model should be environmentally friendly. The smoke emitted during cooking in the oven is captured through distillation, resulting in oil fuel. The conversion brings two benefits, namely obtaining plastic grains and oil fuel. The process includes determining the quantity of oil fuel by measuring the volume obtained from the distillation of the smoke while burning plastic waste. Furthermore, the plastic waste processing process takes 2 hours for each iteration. Data was collected over one month, from August 19 to September 16, 2023.

Hazardous plastic waste is a major concern due to its inherent resistance to decomposition. Plastics show a degradation process when introduced into the soil, with certain varieties necessitating up to a century to break down fully. In this context, the utilization causes pollution of the soil, groundwater, and subterranean ecosystems. The toxins from plastics can permeate the soil, resulting in adverse effects on soil-dwelling organisms and the bacteria important for decomposition. This disrupts subterranean water pathways and diminishes soil fertility by obstructing the natural circulation of air within the soil (Lestari et al., 2019). Various plastic items such as cracked packaging/bags, televisions, refrigerators, PVC pipes, laminated plastics, toothbrushes, children's toys, machinery, and pesticides contribute to this problem. The improper use of plastics can lead to various health issues, including the potential for cancer and tissue damage in the human body (carcinogenicity) (Wang et al., 2023). Various research has linked low levels of bisphenol-A in plastic waste to human health impacts such as decreased testosterone levels, increased prostate levels, breast cancer, and an increased incidence of hyperactivity (Karuniastuti, 2013).

In this context, the volume of waste from Yogyakarta city sent to the landfill (TPA) in Piyungan by the end of 2022 was approximately 300 tons per day, with around 75 tons per day (25%) being plastic (Portal Berita Pemerintah Kota Yogyakarta - Pemkot Yogya Gandeng Mitra Kelola Sampah Residu Plastik, 2023). Furthermore, the increase in plastic usage results from technological, industrial, and population changes. The government can only manage 20-30% of plastic waste, with the rest disposed in landfills. The growing quantity can become a serious issue when a solution is not found and the most popular method for managing plastic waste has been the 3R approach (Reuse, Reduce, Recycle) (Narto and Suparno, 2020).

Plastics have largely been removed from the classification of toxic or hazardous materials. However, additives used to modify the properties of commercial plastics can leach into the environment (Seay 2022). With advancements in the high-tech era, the industry has already created many packaging products made from plastic that have been environmentally friendly modified. According to the Indonesian Law Number 18 of 2008 on Waste Management, waste is residue from human daily activities and natural processes. Therefore, the decline in environmental quality is impacted when the issues are not properly managed. Plastics are made from petrochemicals, which are unsuitable to be reintroduced into the surrounding ecosystems. Scientific research indicates these chemicals are toxic to humans (Nagy and Kuti, 2016).

In this context, spilled, burned, or discarded plastics break down into toxic chemicals. Gradually, these chemicals seep into the soil, water, and air and are absorbed by plants and animals. This can lead to congenital disabilities, hormone imbalances, and cancer (Pavani and Rajeswari, 2014). According to (Masrida, 2017), environmental pollution includes the clogging of irrigation channels, river narrowing leading to flooding, and burning that can produce highly dangerous and toxic dioxins, posing risks to human health and causing public health issues. Open waste burning is a source of air pollution with many negative environmental and health impacts (Bensusan et al., 2019). Environmental advocates recommend that the public and the government implement regulations on the use of plastic bags and charge for their disposal.

Accumulating household waste, especially plastics, can lead to new health issues. Water stored in single-use plastic bottles may contain mosquito larvae that can cause dengue fever (Sukadaryati and Andini, 2022). Public indifference or negligence towards waste management also leads to bad habits and creates disasters. Greenpeace explains that plastic waste can break down into small particles known as microplastics, with sizes ranging from 0.3 to 5 mm. These tiny particles are inherently hazardous penetrating the bodies of living creatures, including humans (Narto and Suparno, 2020). Potential human health impacts may include cancer, stroke, and respiratory diseases. Exposure to microplastics and chemicals can accumulate in the food chain, potentially affecting the entire ecosystem, including the soil's daily food sources.

Based on research conducted by Greeneration Indonesia in 2008, both methods reduce plastic waste in Indonesia by up to 70 days per year. Finally, the government has implemented a plastic bag inspection policy (Kalali et al., 2023). The managing efforts include minimizing the use of plastics and using cloth bags when shopping. The alternative management method is the processing machine model. This machine can transform waste into plastic grains with a higher market value, as well as oil fuel, which is useful as a fuel source. The processing is a preventive measure to control environmental pollution and public health issues.

According to Ganefati (2016), the processing of plastic bag waste, which results in grains and liquid smoke (oil fuel) as a wood preservative, uses the "Oven Distillator" device with one distillation tube. The results can enhance the economic value of plastic waste and produce a wood preservative. This research was conducted to develop machine models with the addition of distillation tubes for testing the capability to determine the best method for plastic waste processing. A cost analysis was also performed to assess the achievement of the Break-Even Point (BEP) for each model.

Cost analysis is a component used to determine the equivalence of generated and incurred costs (Cemil, 2023). The production of plastic grains and oil fuel presents the challenges. For instance, mixing plastic grains with cement and sand result in paving, making it more beneficial and increasing economic value. Furthermore, plastic waste processing can become an industry capable of creating new economic opportunities through the use of this machine. Production and distribution can generate employment opportunities across various sectors (Wang et al., 2023).

Environmental pollution by plastic waste has an impact on health problems and environmental destruction, so plastic waste needs to be processed using a plastic waste processing equipment model that can increase economic value. The renewal of this study is to produce plastic waste processing equipment to produce plastic grains and fuel oil in an effort to increase the economic value of plastic waste and prevent environmental pollution.

1.2 Objective

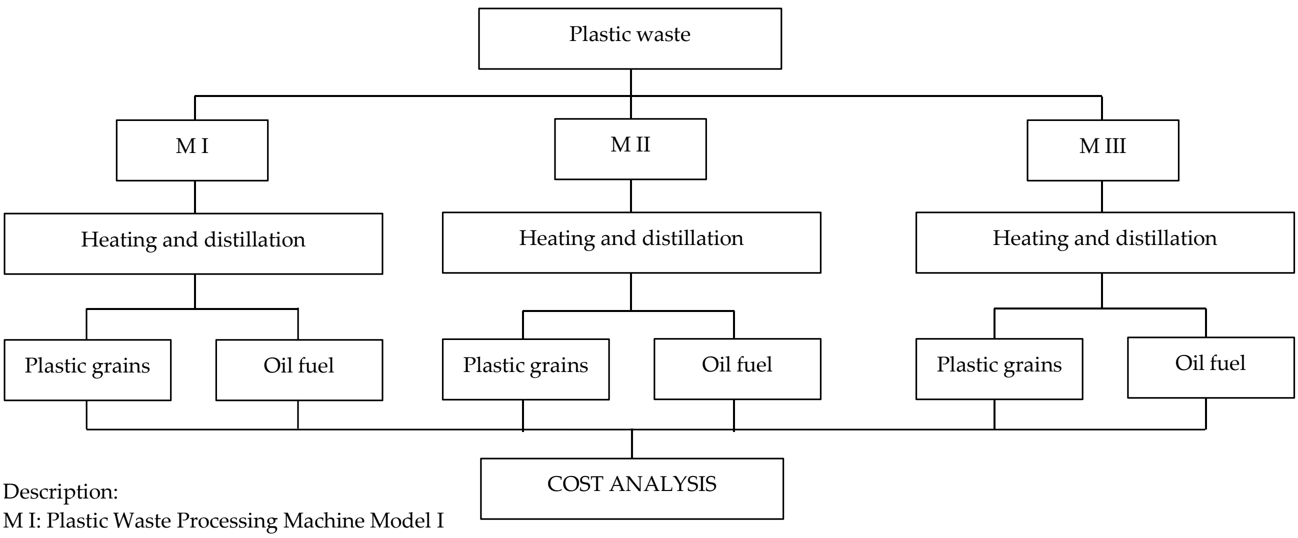
The objective of this research was to compare 3 (three) models of plastic waste processing machines in producing plastic grains and oil fuel, as well as to conduct the cost analysis. The machine models (Type 1, 2, and 3) are with one, two, and three distillation tubes, respectively. The cost analysis was calculated through the return on investment.

2. METHODOLOGY

2.1 Testing of the Model Machine

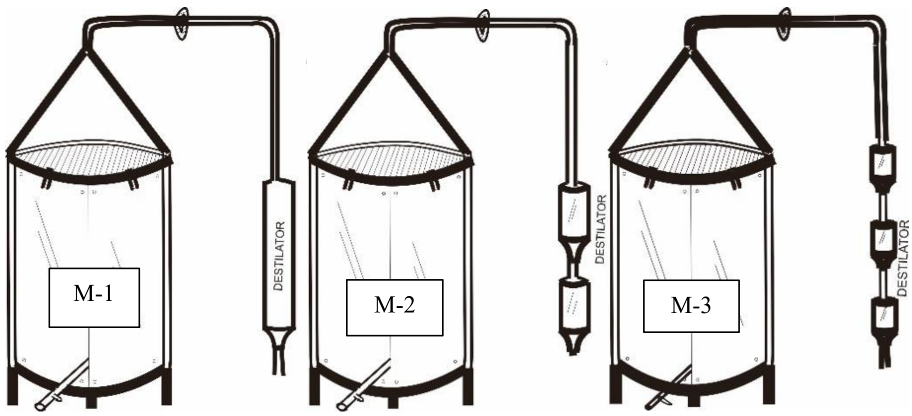
A waste bank is a facility used for collecting segregated waste through a storage system including cashiers and customers (Hapsari et al., 2019). The increasing quantity naturally leads to numerous issues that require management, such as transforming into valuable materials. Waste management with a library system is expected to aid the government in enhancing the economy of the community. The research location is the Sembada Waste Bank in Donokerto, Turi, Sleman.

This research uses a machine model designed to produce plastic grains used as paving stones and oil as a substitute for kerosene. The sample population consists of 60 kg of plastic from the waste bank, with a breakdown of 3.5 kg per treatment, 3 samples, and 6 replications. After processing, the plastic is transformed into grains and oil fuel. Each grain is weighed and measured, and the measurement results are recorded in a table showing the mass of plastic grains and the volume of oil fuel. The obtained data is subjected to statistical normality testing using the Kolmogorov-Smirnov test. A multivariate ANOVA is conducted at a significance level of 95% (α = 0.05) when the data follows a normal distribution. The complete research conceptual framework is depicted in Figure 1. The process conditions for each model (Figure 2) are model-I the cooling process in 1 tube, model-II through cooling process in 2 tubes, and model-III through the cooling process with 3 tubes. All three produce the same fuel oil.



Description:
M I: Plastic Waste Processing Machine Model I
M II: Plastic Waste Processing Machine Model II
M III: Plastic Waste Processing Machine Model

Figure 1. Research Flow Diagram



Description :
M-I: one distillation tubes
M-II: two distillation tubes
M-III: three distillation tubes

Figure 2. Schematic diagram of the process

2.2 Cost Analysis

Break event points can generally be calculated by three methods i.e the equation method, the contribution margin method, and the graphical method. The three models of the distillation are smoke-cooling devices (distillations) that produce fuel oil. This is basically an approach that has the same result, but the three methods have differences in the form and variation of the contribution income statement equation. The method used in the plastic waste processing equipment model uses the equation method.

The Equation Method is a method based on the income statement approach. With the following basic equation (Halim, 2011): Total Income is equal to Total cost. Total income is the sum of Variable costs + Fixed costs. Calculating BEP uses the BEP formula in product units, namely the division of total fixed costs and selling prices per unit of product and variable costs of each unit of product. In a break-even state the operating profit is equal to zero, so it will result in the number of products (in units and units of money sold) sold reaching the break-even point plus fixed costs.

3. RESULTS AND DISCUSSION

Heating and distillation of plastic waste in machine models are conducted at a temperature of 100°C. The first and second fuel products are orange and brown, as shown in Figure 3. The color of the immortal material is different from the fuel obtained (Pannucharoenwong et al., 2023), which is dark orange, using plastic bag waste. Therefore, this research through the temperature heating process significantly improves quality by using plastic waste from bottles.

3.1 Comparison of the Plastic Waste Processing Machine Models

Plastic waste should be recycled to produce economically valuable items to minimize the environmental impact. This research's model can process waste into plastic grains and oil fuel. The calculations yield plastic grains of 97.3% because the production process is conducted in a closed manner through a drying oven. This allows most of the plastic waste to be processed while a small portion (2.03%) is converted into oil fuel, as shown in Figure 5, Figure 6, and Table 1.

Based on the Figure 5, the highest plastic grain weight is found in the fifth repetition of Model III, totaling 3.56 kg. The lowest weight is in the fourth repetition of the third model, amounting to 1.8 kg. Utilization of plastic waste processing into plastic grains that can be used as an asphalt mixture. This can be a solution to overcome waste problems in the community.

Based on the Figure 6, the highest and lowest volumes of oil fuel is found in the fourth version of Model III and the third sample, amounting to 73 ml and 1.8 kg, respectively. According to Syamsiro (2015), oil fuel derived from plastic waste has a good potential as a substitute for conventional fuels such as gasoline and diesel.

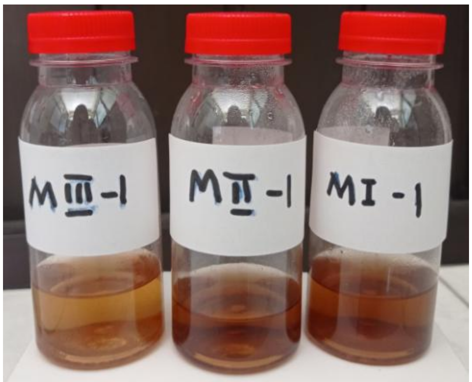


Figure 3. Oil fuel obtained from the models of processing machine

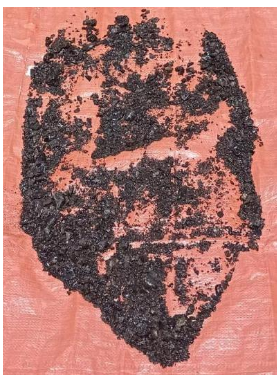


Figure 4. Plastic grains obtained from the models of processing machine

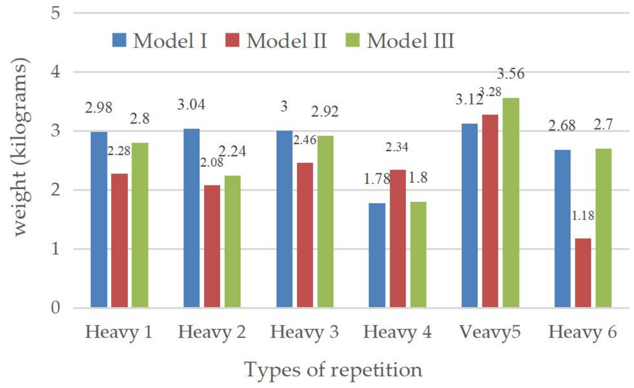


Figure 5. The production of plastic grain (Kg) from three models of processing plastic waste

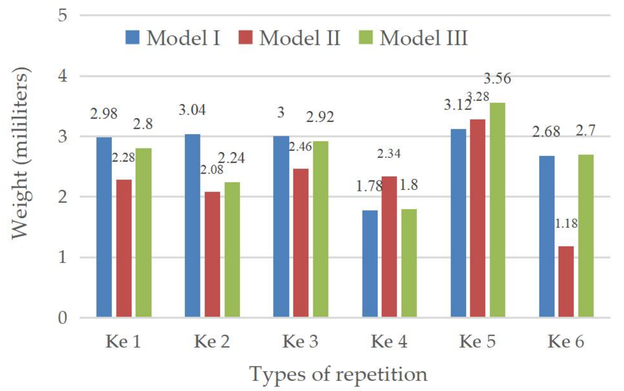


Figure 6. The production of oil fuel (mL) from three models of processing plastic waste

Table 1. Average Weight of Plastic Grains and Volume of Oil Fuel from Plastic Waste Processing

Model	Plastic Grains (kg)	Oil Fuel (ml)
I	2.76	42
II	2.27	41.17
III	2.67	51

The average quantity of plastic waste processed into grains is 3.5 kg. The highest average quantity is 2.76 kg and 51 ml for Model I and III, respectively. The use of the model is a closed process in the plastic waste heating and oil fuel production stages. The smoke generated is cooled, preventing the release into the air. Furthermore, the conduction of open burning produces toxic pollutants called dioxins. These compounds are extremely hazardous when inhaled by humans and cause various diseases, including cancer, hepatitis, and nervous system disorders. In this context, the processing machine model does not contaminate exhaust smoke. The emitted smoke is subjected to a cooling process, transitioning from a gaseous to a liquid phase (Kalali et al., 2023).

Based on the observations, no smoke is emitted and this condition implies the conduction of a cooling process to form oil fuel. Another advantage of using the machine model is its ability to minimize the negative impacts and provide highly beneficial results for the community and the environment. The results of the ANOVA test show a p-value of 1.000 ($p \geq \alpha = 0.050$), indicating no significant difference in the quality of plastic grains and oil fuel. Therefore, the three models produce the same plastic grains and oil fuel. The grains can be used to make paving stones or asphalt, and oil fuel is proper for combustion. These are polycyclic aromatic hydrocarbons, oil, and dioxins (Ajay et al., 2022). Polycyclic aromatic hydrocarbons produce a very pungent odor, a substance that can repel insects to prevent damage to wood. The oil in resin fuel can also be used to repel termites, hence preventing oiled wood destruction. Dioxin compounds contained in plastic fuel are toxic to living organisms and are not favored by termites. In this context, this study is supported by test results showing that fuel can preserve wood, especially termite resistance. Resin fuel contains various compounds used as antifungal, antivirus, and toxic compounds. Therefore, one of the advantages of wood fuel oil is its use as a termite-resistant preservative (Praveenkumar et al., 2023)

3.2 Cost Analysis

Plastic waste can be transformed from a solid to a liquid and gas form based on the heating principle. This cannot be conducted through burning because the process is incomplete, resulting in carcinogenic compounds. Therefore, plastic waste should be burned at a temperature of 1,000°C using a large furnace.

Unit cost analysis is the result of dividing the total operational cost by the amount of waste processed within the same time frame. This is measured in rupiah per kilogram since the waste is in kilograms (a unit of weight). Unit cost is crucial, especially for calculating the requirements for processing within a specific period (Kustanti et al., 2020).

The estimated average cost of raw materials (plastic waste) is IDR 200, resulting in products such as plastic grains and oil fuel with an estimated average price of IDR 2,500 and IDR 25,000 per liter. The cost required to process plastic waste with the machine model includes raw material costs, fuel, and energy. In addition, the average fuel and labor costs are IDR 2,890 and IDR 499, while labor costs contribute 10% of the material and fuel costs or 10% x (IDR 200 x 10.5 kg) + 2,890-) machine = IDR 499.

The production cost required for processing plastic waste using the machine can be calculated by adding the material, fuel, and labor cost = IDR 2,100 + IDR 2,890 + IDR 2,080.5 (Production cost = IDR 4,990). The profit obtained from processing 10.5 kg of plastic waste using the processing machine was obtained at IDR 112,555.5.

The profit obtained from processing 3.5 kg of plastic waste using the Processing Machine Model is IDR 6,318.64. Compared to the estimated price of plastic waste (IDR 290.33), the profit (IDR 6,318.64) from processing increases the economic value by 217.66%. This situation can be described as the machine model being an economically valuable processing tool.

The construction of the Machine Model also included the Break Even Point (BEP) calculation to predict the return on investment. The processing of plastic waste (3.5 kg) takes 2 hours but an 8 hours daily operation produces 10.5 kg and the BEP can be calculated as follows 126 days.

The Break Even Point (BEP) for the Plastic Waste Processing Machine Model will be achieved when routinely processing 1.5 kg of plastic waste per day for 134 days. Considering scale-up and mass production of plastic grains from the processing process can be economically viable. However, a detailed economic analysis is required to ensure feasibility. In this context, recycling offers additional environmental benefits, such as lower emissions, waste management, and reduced soil degradation at landfill sites (Saleem et al., 2023).

Table 2. The BEP for Each Plastic Waste Processing Machine Model for 8 Hours per Day Operation

Model	Machine price (IDR)	Profit in 2 hours (IDR)	Profit in 8 hours (IDR)	BEP (days)
M I	20,000,000	113,563	454,252	44
M II	20,000,000	106,937	427,748	47
M III	20,000,000	132,512	536,700	35

4. CONCLUSION

The findings of this research showed the potential of plastic waste obtained from waste bank community in Sleman Regency, Yogyakarta Province, to be converted to plastic grains and oil fuel using 3 (three) models processing machine. Results of the analysis of variance showed that there were no significance different statistically on the quantity of plastic grains and oil fuel obtained with the variation of plastic waste processing model. Application of machine model III in this research has given more cost-effective compare to model I and II with 10.5 kg of plastic waste for 8 hours/day routine operation. However, detailed economic calculation is required to feasibility of these models in industrial scale. This research could be as a prelimanary basis for the development of utilization process of plastic waste, especially in Yogyakarta Province. The developed method could become a new strategy for waste management in small community that will enhancing the added value of plastic waste and its the economic aspect.

There was no influence of the variation in plastic waste processing machine models (I, II, and III) on the quantity of plastic grains ($p > \alpha$). There was no influence of the variation in models (I, II, and III) on the quantity of oil fuel ($p > \alpha$) Statistically, all models (I, II, and III) had equal capability in producing plastic grains and oil fuel. The BEP for Models I, II, and III operating for 8 hours per day in processing 10.5 kg of plastic waste, was achieved in 44, 47, and 35 days, respectively Based on cost analysis, the best model for plastic waste processing was Model III.

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REFERENCES

Ajay, S. V., Kirankumar, P. S., Varghese, A., & Prathish, K. P. (2022). "Assessment of Dioxin-Like POP's Emissions and Human Exposure Risk from Open Burning of Municipal Solid Wastes in Streets and Dumpyard Fire Breakouts." Exposure and Health 14(3): 763–78. https://doi.org/10.1007/s12403-021-00450-4.

Reyna-Bensusan, N., Wilson, D. C., Davy, P. M., Fuller, G. W., Fowler, G. D., & Smith, S. R. (2019). Experimental Measurements of Black Carbon Emission Factors to Estimate the Global Impact of Uncontrolled Burning of Waste. Atmospheric Environment, 213, 629-639.

Wang, B., Wang, X., Liu, Y., Zhang, Q., Yang, G., Zhang, D., & Guo, H. (2023). Phytic Acid-Fe Chelate Cold-Pressed Self-Forming High-Strength Polyurethane/Marigold Straw Composite with Flame Retardance and Smoke Suppression. Polymer Degradation and Stability, 208, 110269.

Koyunoğlu, C. (2024). The Economic Case for Blend Fuels: A Cost-Benefit Analysis in The European Context. Sustainable Technology and Entrepreneurship, 3(2), 100060.

Wang, B., Wu, E., Rassloff, D., Moore, M., Bridger, P., & Garrison Jr, L. P. (2023). Estimating the Potential Economic Impact of Tissue Valve Replacement for Heart Valve Disease in China: Patient-Level and Population-Level Cost-Benefit Simulation Analyses. Value in Health Regional Issues, 35, 19-26.

Farin, S. E. (2021). Penumpukan Sampah Plastik yang Sulit Terurai Berperngaruh pada Lingkungan Hidup yang Akan Datang. Universitas Lambung Mangkurat, Banjarmasin.

Ganefati, S. P., Hendrarini, L., & Windarso, S. E. (2011). Oven Destilator Pengolah Sampah Plastik Ramah Lingkungan "Pemanfaatan Asap Cair Hasil Olahan Oven Destilator untuk Pengawetan Kayu". Jurnal Teknologi Lingkungan, 12(1), 85-92.

Halim, A. & Untung, R. (2011). Analisis Investasi/ Abdul Halim. Editor, Rachman Untung. Jakarta: Salemba Empat, hal 207-209.

Hapsari, R. S., Suwasono, E., & Daroini, A. (2020). Bank Sampah sebagai upaya Pemberdayaan Masyarakat. REVITALISASI: Jurnal Ilmu Manajemen, 8(2), 226-231.

Kalali, E. N., Lotfian, S., Shabestari, M. E., Khayatzadeh, S., Zhao, C., & Nezhad, H. Y. (2023). A Critical Review of the Current Progress of Plastic Waste Recycling Technology in Structural Materials. Current Opinion in Green and Sustainable Chemistry, 100763.

Karuniastuti, N. (2013). "Bahaya Plastik terhadap Kesehatan dan Lingkungan." Swara Patra: Majalah Pusdiklat Migas 3(1): 6–14. http://ejurnal.ppsdmmigas.esdm.go.id/sp/index.php/swarapatra/ article/view/43/65.

Kustanti, R., Rezagama, A., Ramadan, B. S., Sumiyati, S., Samadikun, B. P., & Hadiwidodo, M. (2020). Tinjauan

Nilai Manfaat pada Pengelolaan Sampah Plastik oleh Sektor Informal (Studi Kasus: Kecamatan Purwodadi, Kabupaten Grobogan). Jurnal Ilmu Lingkungan, 18(3), 495-502.

Lestari, T., Indriastuti, N., Noviatun, A., Hikmawati, L., & Margana, M. (2019). Lentera: Inovasi Pengolahan Sampah Plastik di Indonesia.

Masrida, R. 2017. "Kajian Timbulan dan Komposisi Sampah Sebagai Dasar Pengelolaan Sampah di Kampus II Universitas Bhayangkara Jakarta Raya." Journal of Env. Engineering & Waste Management 2(2): 69–78. http://dx.doi.org/10.33021/jenv.v2i2.221.

Agnes, N., & Rajmund, K. U. T. I. (2016). The Environmental Impact of Plastic Waste Incineration. AARMS–Academic and Applied Research in Military and Public Management Science, 15(3), 231-237.

Narto, S., & Suparno, B. A. (2020). "Evaluasi Program Corporate Social Responsibility Pelatihan Ecobrick dalam Mengelola Sampah Plastik." Jurnal Ilmu Komunikasi 17(3): 295-306. https://doi.org/10.31315/jik.v17i3.3778

Pavani, P, & Rajeswari, R, T. (2014). "Impact of Plastic on Environmental Pollution." Journal of Chemical and Pharmaceutical Sciences 94(3): 87–93.

Pannucharoenwong, N., Duanguppama, K., Echaroj, S., Turakarn, C., Chaiphet, K., & Rattanadecho, P. (2023). Improving Fuel Quality from Plastic Bag Waste Pyrolysis by Controlling Condensation Temperature. Energy Reports, 9, 125-138.

"Portal Berita Pemerintah Kota Yogyakarta - Pemkot Yogya Gandeng Mitra Kelola Sampah Residu Plastik." 2023. Adminwarta. https://warta.jogjakota.go.id/detail/index/27980#:~:text= Volume sampah Kota Yogyakarta pada akhir 2022 yang,berkurang 75 ton%2Fhari atau menjadi sekitar 225 ton%2Fhari. Accessed 21 August 2021.

Seay, J. R. (2022). The Global Plastic Waste Challenge and How We Can Address It. Clean Technologies and Environmental Policy, 24(3), 729-730.

Praveenkumar, T. R., Sekar, M., Pasupuleti, R. R., Gavurová, B., Kumar, G. A., & Kumar, M. V. (2024). Current Technologies for Plastic Waste Treatment for Energy Recovery, It's Effects on Poly Aromatic Hydrocarbons Emission and Recycling Strategies. Fuel, 357, 129379.

Saleem, J., Tahir, F., Baig, M. Z. K., Al-Ansari, T., & McKay, G. (2023). Assessing the Environmental Footprint of Recycled Plastic Pellets: A Life-Cycle Assessment Perspective. Environmental Technology & Innovation, 32, 103289.

Sari, G.L. (2017). "Kajian Potensi Pemanfaatan Sampah Plastik Menjadi Bahan Bakar Cair." Al-Ard: Jurnal Teknik Lingkungan 3(1): 6–13.

Sukadaryati, S., & Andini, S. (2021). Upaya Pengelolaan Minim Sampah Rumah Tangga: Management Effort for Minimum Household Waste. Jurnal Silva Tropika, 5(2), 419-432.

Syamsiro, M. (2015). Kajian Pengaruh Penggunaan Katalis terhadap Kualitas Produk Minyak Hasil Pirolisis Sampah Plastik. Jurnal Teknik, 5(1), 47-56