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Life Cycle Assessment (LCA) and Environmental Impacts Towards Plastic Waste by Using Pyrolysis

Amirah Ayu Kartika [a], Low Siew Chun[a*], Suzylawati Ismail[a**]

[a]*School of Chemical Engineering, Universiti Sains Malaysia, Engineering Campus, 14300, Nibong Tebal, Penang, Malaysia*

[*]*(chsuzy@usm.my)*

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Abstract – Plastic waste pollution is a developing global issue that must be addressed immediately. Despite increased recycling rates, most plastic still ends up in landfills, contaminating the environment and destroying ecosystems. Pyrolysis technology offers a potential solution to this issue by dissolving plastic trash into its component parts and producing electricity without releasing harmful pollutants into the atmosphere. Since it can be used without emitting toxic gases into the atmosphere, pyrolysis is a unique and sustainable method of energy recovery. The use of accessible and affordable bentonite clay in pyrolysis could considerably help in the reuse of plastic wastes. This review paper provides a comprehensive overview of the current state of knowledge on pyrolysis technology for plastic waste management, with a specific focus on the use of life cycle assessment (LCA) methodology. The study reviews pyrolysis research from the past and now, discussing its environmental advantages, catalytic and thermal yield, and potential for further study. The report also explores several possible pyrolysis technology constraints and other plastic waste end-of-life solutions. The findings of the review point out the promising potential of pyrolysis as an eco-friendly technique for handling plastic waste and outline areas that require additional study and improvement. The findings presented in this review can be used by policymakers, practitioners, and other stakeholders to solve the plastic waste issue and make well-informed choices.

Keywords – Plastic Waste, Pyrolysis, Life Cycles Assessment (LCA), Environmental Sustainability, Waste Management

1.0Introduction

Plastics are among the materials invented by humans to meet their needs. They are extremely necessary materials used in a wide range of applications that make our daily activities at home, in retail packaging, marketing, building, and healthcare easier because of their availability, chemical stability, lightweight nature, and capacity to be used again. Single-use plastics from the COVID-19 epidemic, like as masks, gloves, containers, medical packaging, and utensils, are clearly having an impact on waste plastic management [1]. Furthermore, as worldwide plastic usage rises, plastic trash has emerged as a significant component of municipal solid waste. As a result, the amount of post-consumer plastic waste (PCPW) in the environment continues to rise. Plastic production on a global scale is projected to be over 300 million tonnes per year, and it is rapidly expanding. In many countries today, garbage generated by the indiscriminate dumping of used plastics accounts for a major fraction of the total waste stream. The fact that marine plastic trash is ingested by aquatic species and known to degrade into microplastics and nano plastics is even more concerning [2]. According to previous research, this has a major detrimental influence on the population and mortality of zooplankton, which is a critical source of energy for the marine environment. Plastic wastes are currently a hazard to the world economy, people, animals, and the environment, particularly in developing countries that lack sophisticated recycling facilities and inadequate policies governing the manufacturing, use, and regulation of plastics.

Plastic trash has been dealt with in a variety of ways, depending on local restrictions and what is socially acceptable, including recycling, reuse, landfill disposal, and conversion to energy via pyrolysis. Pyrolysis is the long-term management of plastic waste and the generation of liquid oil as an energy source, as well as solid char and gases as value-added products. The heat breakdown of complex compounds or long chain hydrocarbons into smaller molecules or shorter chain hydrocarbons is involved in this process. Since the production of plastics uses up to 6% of global petroleum production, extracting fuel oils from waste plastics can also assist reduce dependency on fossil fuels.

Waste plastics are resources that have significant societal and economic benefits, including job creation, growth, innovation, and sustainability. Considering dumping and incineration are illegal in some countries, the best waste management alternative is energy recovery from waste resources via pyrolysis. Despite all of the environmental issues associated with non-biodegradable waste plastics, it is vital to reconsider their conversion to energy fuels via thermal or catalytic pyrolysis. Prior to review, some good review papers had previously been communicated by [3]. The current review, on the other conjunction, is presented comprehensively, discussing the pyrolysis of the most commonly used polymers, including the factors that affect the pyrolysis process, the life cycle assessment (LCA), environmental consideration of the current situation, and future perspectives on this issue, which was not covered in detail in the previous review articles. As a result, this review could serve as a resource for researchers looking to logically design experiments and develop novel ways.

2.0 Methodology

The study adheres to ISO 14040/44 LCA guidelines (ISO, 2006a, 2006b). The elements that follow describe the study's goal and scope, the inventory data, and the assumptions used to estimate impacts [4].

2.1 Goal and Scope

The goal scope based on Zhu et. al [5], considering the environmental effects of manufacturing systems. The carbon footprint, GHG emissions, environmental performance, carbon sequestration potential, environmental impacts and efficiencies, air pollutants, as well as barriers, climate change, and health implications are some of the terms utilized to define the goal and scope of LCA pyrolysis. A rigorous evaluation of the potential environmental impacts from this process, including factors such as energy and water usage, emissions to air, water, and soil, and hazardous waste generation, will be completed to further inform the feasibility of the pyrolysis process [6].

2.2 LCA Analysis

LCA is currently the most widely used tool for assessing the environmental performance of products, and it applies to all stakeholders worldwide, including government, industry, non-governmental organizations (NGOs) and academia [7]. In addition, LCA must be understood and utilized in a balanced manner in order to ensure long-term success. Several life cycle assessment

(LCA) studies have looked into the environmental effects of various end-of-life procedures for plastic garbage, but have frequently reached conflicting conclusions.

LCIA (Life Cycle Inventory Analysis) environmental categories can be divided into mid-point indicators and end-point indicators. In general, mid-point categories are used to indicate the environmental consequences of the life cycle, such as global warming potential (GWP), acidification potential (AP), ecotoxicity potential (EP), eutrophication potential (ETP), water depletion potential (WDP), and fossil energy potential (FE) [8]. GWP is the most widely utilized impact in LCA analysis. Byproducts of plastic waste pyrolysis exhibit qualities similar to fossil fuels. The yields of the AC and SP processes are determined using experimental data, with the gas composition approximated from existing literature [9].

2.3 Life Cycle Interpretation (LCI)

The interpretation of results is built upon determining significant concerns, assessing completeness, sensitivity, and consistency, and any stage change may impact the LCA results in the same system. Sensitivity analysis, according to ISO standards, ought to emphasize on the most significant issues in order to identify the impact of changes in assumptions, techniques, and data. The independent variables in LCA can be parameter value, allocation rule, system boundary, model selection, or procedure selection. The dependent variables in a comparative study can be output parameter values or alternative priority rankings [10].

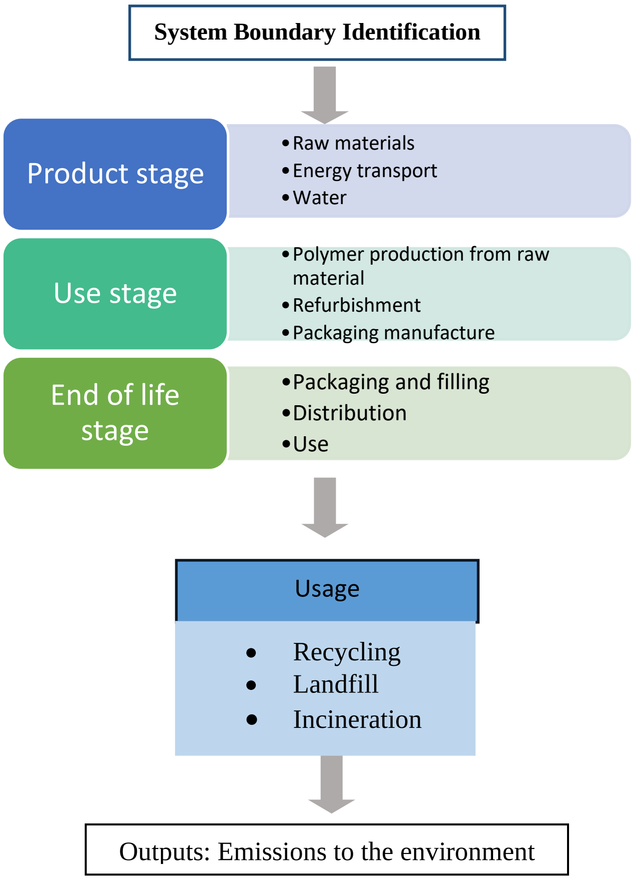

Figure 1: LCA system boundaries

3.0 Results and Discussion

3.1 Landfill disposal

According to prior research, the material acquisition and production stage accounts for more than 95% of the impacts in six categories (CC, TA, FE, PM, TE, and FFD). In this system boundaries, the net greenhouse gas emission and fossil fuel depletion were 2766.9 kg CO2 eq and 2338.3 kg oil eq, respectively, per tonne of plastic trash processed [11]. These effects were caused by the use of fossil fuels such as oil and natural gas, as well as a lack of recovery to offset the overall effects.

Many environmental issues have been raised as a result of the dumping of plastic trash in landfills, particularly in the areas of marine eutrophication, freshwater ecotoxicity, and marine ecotoxicity, all of which are likely connected with the creation of leachate from landfills. The LCA results matched this assumption, with the landfill scenario having comparatively low climate change impacts (111 kg CO2 eq/t waste) when compared to other scenarios. Findings from [12] were in line with the conclusion and showed that 100 kg CO2/tonne of plastics dumped in landfills had a global warming potential.

3.2 Pyrolysis for energy recovery

In this scenario, 1 kg of pyrolysis syngas is expected to replace 0.75 kg of conventional liquefied natural gas (LNG) [13]. In addition, the liquid component of the product stream is delivered to a refinery to be converted into petrol and diesel. As a result, the quantity of each energy product influences the outcome of this situation. Although it did not contribute to any other effect categories, syngas production greatly reduced climate change consequences.

When the complete life cycle of plastics is taken into account in this situation, the environmental benefits derived from energy recovery by pyrolysis are minor when compared to other types of pyrolytic products.

3.3 Environmental Impact Aspects

Life Cycle Assessments (LCA) assesses a product's inputs, outputs, and potential environmental impacts throughout its life cycle. The environmental assessment encourages economic sustainability analysis which it is including financial costs and benefits in order to optimize production flows for sustainable of pyrolysis production [14]. The results in Table 1 show that the amount of particulates matter emitted into the air is greater.

Table 1: Summary of inventory data of MPW for pyrolysis process measured in this study

Item	Flow	Amount	References
Energy use	Electricity for pelleting	0.11	Banivaheb et al.
	Electricity for drying	0.03	
Input material	Mixed Plastic Waste (MPW)	1	Jeswani et al.
Output product	MSW Pellet	0.67	Almeida, et al.
	Char	110	
Emissions to air	Particulates, <2.5 µm	3.28E-07	Lee et al.
	Particulates, >10µm	4.93E-07	
	Water Steam	0.33	

The analysis findings of the emission factors in the production of bio-oil are shown in Figure 3, where CO2 emits at a rate of 66.75 kg/GJ, while CH4 emits at a rate of 0.01 kg/GJ and N2O emits at a rate of 60.0 kg/GJ. When 0.67 kg MPW is pyrolyzed, 66.75 kg CO_2 and 0.01 kg CH4 are released. This explains why the bio-oil production process is the primary source of GHG emissions. Indeed, the primary source of GEG is biofuel production, which accounts for 32.8% of total emissions. The main causes of acid deposition are SO_2, NO_x, and NH_3 [19]

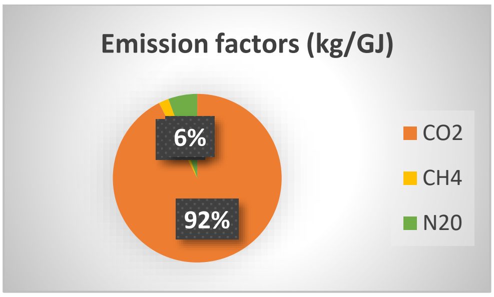

Figure 2: Emission factors of bio-oil production

The findings research indicated that, in comparison to the production of fuels, both recycling techniques have the potential to lessen their negative effects on the environment. According to [20] the proposed integrated FPPW pyrolysis process reduces the amount of plastic waste that would otherwise have to be disposed of, thus improves the pyrolysis process's environmental sustainability, that which can increase the pyrolysis process's revenue stream, and eliminates the use of fossil fuel sources in the conventional MWCNTs synthesis process.

To be discussed among all the calculated categories, the global warming (GW) item had the most significant impact, followed by the terrestrial acidification (TA) factor. The effects on ozone formation, human health (OFH), fine particulate matter formation (FP), ozone formation, terrestrial ecosystems (OFT), terrestrial ecotoxicity (TE), and fossil resource scarcity (FR) were moderate [21]. According to the estimated LCA, converting WMs into oil products via pyrolysis has a significant potential for industrial application with a significant environmental impact, particularly on global warming [22].

4.0 Conclusion

Plastic pyrolysis is an advantageous method for dealing with plastic waste since it reinforces mechanical recycling. This review article provides a detailed and critical look at the negative effects of improper plastic waste management, catalytic pyrolysis, the pyrolysis process of mixed plastic waste, identifying the optimised and strategized life cycle assessment of plastic pyrolysis, environmental considerations that could help preserve the environment and economy, and environmentally friendly prospects.

The following recommendations should be given special consideration in future research. To begin, government incentives are required to avoid the current corporate tax charged on energy from waste (EfW). Second, a possible area for research is the LCA analysis of microalgae pyrolysis; this entails shifting our attention away from end-of-life treatment technologies and towards more sustainable consumption in order to reduce resource depletion and the need for waste management.

Finally, recovering PET and locating the plant near a petrochemical facility may help to enhance the plant's economics and reduce its environmental impact. To ensure the availability of plastic garbage, a comprehensive national supply chain strategy must be developed. Finally, more emphasis should be placed on the value-added products created by plastic pyrolysis.

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