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Current state and future prospects of plastic waste as source of fuel: A review

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ABSTRACT

Due to the depleting fossil fuel sources such as crude oil, natural gas, and coal, the present rate of economic growth is unsustainable. Therefore, many sources of renewable energy have been exploited, but the potentials of some other sources such as plastics waste are yet to be fully developed as full scale economic activity. Development and modernization have brought about a huge increase in the production of all kinds of plastic commodities, which directly or indirectly generate waste due to their wide range of applications coupled with their versatility of types and relatively low cost. The current scenario of the plastic recycling technology is reviewed in this paper. The aim is to provide the reader with an in-depth analysis with respect to the pyrolysis of plastic waste as obtained in the current recycling technology. As the calorific value of the plastics is comparable to that of hydrocarbon fuel, production of fuel from plastic waste would provide a good opportunity to utilize the waste as a better alternative to dumpsites. Different techniques of converting plastics waste into fuel including thermal and catalytic pyrolysis, microwave-assisted pyrolysis and fluid catalytic cracking are discussed in detail. The co-pyrolysis of plastics waste with biomass is also highlighted. Thus, an attempt was made to address the problem of plastic waste disposal as a partial replacement of the depleting fossil fuel with the hope of promoting a sustainable environment.

Contents

Abbreviations: LDPE, low density polyethylene; HDPE, high density polyethylene; PP, polypropylene; PVC, poly (vinyl chloride); PS, polystyrene; PET, poly (ethylene terephthalate); MSW, municipal solid waste; MPW, municipal plastic waste; BTX, benzene, toluene and xylene; BET, Brunauer, Emmett and Teller method (for surface area analysis); LHV, lower heating value; CV, calorific value; PAH, polycyclic aromatic hydrocarbon; TMAH, tetramethyl ammonium hydroxide; TPA, terephthalic acid; AIBN, azoisobutylnitrile; RDF, refuse-derived fuel; HBL, hard burnt lime; PLA, poly(lactic acid); CSBR, conical spouted bed reactor; FCC, fluid catalytic cracking; FTIR, Fourier-transformed infrared; MAP, microwave assisted pyrolysis; VGO, vacuum gas oil; LCO, light cycle oil; PBD, polybutadiene; LPG, liquefied petroleum gas

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1. Introduction

The invention of plastics is a major milestone that led to improvement in the quality of the lives of human beings. Since its first synthesis in early 1900s, plastics have substituted many types of materials such as wood, metals and ceramics in production of consumer products, as they are light, durable, resistant to corrosion by most chemicals, diversity of applications, ease to processing and low cost. Other than the mentioned advantages of plastics, studies have shown that plastic-based products are responsible for reduction in cost of production in different fields of human endeavor [1]. In transportation, for instance, the use of plastic in manufacturing vehicles components and accessories reduces the weight, hence the fuel consumption of vehicles. Human's dependence on plastic-based materials is reflected in Table 1, which indicates the production of each type of plastic in 2012.

In spite of the above mentioned benefits derived from plastics, environmental problems arise due to accumulation of plastic waste from the onset of their invention. As plastic waste virtually does not degrade, it occupies the landfill space for hundreds years after their disposal. According to World Bank [4], plastic waste accounted for 8–12% of total municipal solid waste (MSW) generated in different countries all over the world. The actual percentage varies according to the income level of the people in the country. It was also estimated that global plastic waste generation in 2025 will increase to 9–13% of total MSW, which again varies according to country. In order to reduce the adverse effects brought by plastic waste, efforts have been made in promoting recovery of plastic waste for recycling. In average, 50% of the plastic waste generated in Europe is recovered, while the rest is sent to landfills [1]. The high recovery rate is largely contributed by the nations where partial or total ban is practiced in the landfilling of high calorific waste. However, it was also pointed out that all recycling alternatives for plastic waste are currently more costly than landfilling and incineration (excluding energy recovery). Thus, alternatives with more economical benefits are needed to increase the involvement of private companies in the plastic waste recycling.

The recycling processes have been categorized under four main types, namely primary recycling (in-plant recycling), secondary recycling (mechanical recycling), tertiary recycling (chemical recycling), as well as quaternary recycling (energy recovery) [5]. However, each of these methods has its limitations and can be adopted for different purposes to a certain extent. Among all the four methods of recycling, only chemical recycling conforms to the principles of sustainable development because it leads to the formation of the raw materials from which the plastics are originally made. Since chemical recycling process is able to recover the energy content of the plastic in the form of liquid and gas, it is increasingly gaining the attention of more researchers. Chemical recycling may provide a solution towards the energy crisis. Since industrial revolution, the world has been heavily dependent on petroleum and natural gas resources in almost all activities, especially power generation for industrial applications. In addition, fossil fuels are still the main energy sources for vehicles, agriculture and housing. However, petroleum is a non-renewable energy source, and is expected to be depleted in a foreseeable future due to heavy utilization for industrial activities as the only means of large and cheap source of energy. In order to address the problem of depleting fossil fuel, concerted efforts have been made to develop affordable renewable energy, including solar energy, hydropower, geothermal, wind and so forth. Such efforts are recognized by the government of different countries and incentives were offered to the developers in the form of feed-in tariffs [6–13]. Meanwhile, the potentials of converting plastic waste to fuel is yet to be recognized, although such potential had been discussed in a number of reviews, as summarized in Table 2.

This review presented an articulated summary (concise review) of the recent progress in production of fuels and chemicals from virgin and post-consumer plastic waste, with the main focus in pyrolysis, as well as co-pyrolysis of plastic waste with other materials. The aim is to provide the reader with an in-depth analysis with respect to the recycling techniques of biomass and plastic solid waste (PSW) existing today and proposed techniques likely to be popular in the foreseeable future. Herein, a concise summary and comparison was made, in a tabular form, of the different processes versus yield, parameters and rector types which is a novel approach to review writing in the pyrolysis of plastics waste.

Table 1
Annual production of different plastics in 2012 [2,3].

Type of Plastic	PE	PP	PVC	PET	PS	EVA
Production (million tonnes) [2,3]	65.41	52.75	37.98	19.8	10.55	2.8

2. Types of reactors and process design in plastic waste pyrolysis

Over the past few decades scientists have discovered that in the absence of oxygen, plastic, which consist of long chain polymer chain, can be fragmented at high temperature to form oligomers. The term pyrolysis was used to refer to such process, although it normally refers to thermochemical decomposition of organic materials at high temperature in the absence of oxygen. In some context, the term “cracking” is used instead of pyrolysis. Nowadays, it is a common practice to differentiate thermal pyrolysis from catalytic pyrolysis. The former refers to the decomposition of polymers due to the application of heat alone, while the latter refers to the processes where catalyst is utilized to alter the reaction mechanism of pyrolysis, hence the products yield and composition. Some recent studies focused on plastics waste pyrolysis using different processes are shown in Table 3.

2.1. Batch and semi-batch reactor

In most researchers utilized batch or semi-batch reactors for thermal and catalytic pyrolysis of virgin plastic, as well as post-consumer plastic waste, as it is easy to control the process parameters. Some of the important parameters that were identified include reaction temperature, mass ratio of plastic:catalyst, and reaction time. The temperatures used for the process ranged in 300–900 °C, and the reaction time 30–90 min [21,29]. In case of catalytic pyrolysis, mass ratio of reactant: catalyst varied from 30:1 to 2:1 was used to increase the product yield and selectivity [21,30].