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ScienceDirect

Energy Procedia 61 (2014) 1681 – 1685

Energy Procedia

The 6th International Conference on Applied Energy – ICAE2014

Utilization of polymer wastes as transport fuel resources- a recent development

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Abstract

Used plastic polymer is one of the major wastes in the developed countries like Australia. Australia is spending a lot of money each year to process solid wastes in land filling which are not biodegradable and can be a threat to the environment in the long run. About 19% of the overall plastic wastes are recycled every year in Australia. The incineration processes of plastic wastes lead to severe air pollution, too. Since the plastic polymers are originated from the petroleum resources, the possible technologies of converting them into fuel have drawn attention to meet the future fuel demand. Thus, converting the plastic polymers into transport fuel through a cleaner combustion process will contribute to saving environment. It has been observed that the thermal fuel conversion technology, known as thermolysis and the dissolution process of plastic polymers into an acceptable bio-solvent can lead to reduction of plastic wastes effectively. This paper presents a review on various thermolysis processes and the dissolution effect of various plastic polymers into bio-solvents. The technical features of converting polymers into fuel through appropriate and optimal technologies for the fuel production also have been analyzed. The authors have undertaken further studies on developing alternative fuel processing technologies to utilize polymer wastes as a resource, thus reducing environmental contaminant in an effective way.

Peer-review under responsibility of the Organizing Committee of ICAE2014

Keywords: Waste reduction, Plastic waste, Waste-to-energy, Pyrolysis, Bio-solvent, Fuel processing, Alternative fuel

1. Introduction

Economic growth, wrapping or packaging ranges of industrial products and change of consumers' behaviour on carrying goods have resulted in rapid increase in generation of waste plastics in the world. The world's annual consumption of plastic materials has increased from around 5 million tons in the 1950s to nearly 280 million tons in 2012 [1]; thus, producing 56 times more plastic today than 62 years

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Peer-review under responsibility of the Organizing Committee of ICAE2014
doi:10.1016/j.egypro.2014.12.191

ago. This implies that more resources are being used to meet the increased demand of plastic, and on the other hand, more plastic waste is being generated. Plastics have been accepted as essential material for both in households and industrial activities due to their durability, higher load carrying capacity, less expenditure and availability. Based on their properties various types of plastic are used distinctly in specific purposes, such as packaging, material carrying, as a replacement of many mechanical components previously manufactured with metals, etc. Since plastic polymers originated from the petroleum resources, the possible technologies of converting them into fuel have been brought into attention to meet the future fuel demand to reduce the continuing fuel import demand in various countries. Conventional plastic polymers, which are mainly produced (~99%) from hydrocarbon feedstocks [2], are the predominant interest to use as renewable raw material for energy production due to possessing equivalent heating value. Unfortunately, refineries are technologically limited to accept only a very narrow range of liquid hydrocarbons with very specific properties and minimal contaminants for optimal production of desired petroleum products [3]. Hence, making best use of plastic polymer wastes is a necessity than putting them in land filling as well as in uncontrolled incinerators. Various thermochemical recycling processes can lead to accomplish an effective recycling of the waste plastic polymers by converting them into transport fuel grade hydrocarbons. In this article, focus has been given to the technical features of most of the effective technologies of converting waste plastic polymers into fuels of gasoline or diesel fuel grade to determine appropriate and optimal technologies for the transport fuel production.

2. Waste Polymer to Energy Recovery

The catalytic cracking, non-catalytic cracking (i.e. thermolysis: pyrolysis, gasification and hydrogenation), steam degradation, etc. are under industrial applications to produce energy from waste plastic polymers [4]. Mixture of heterogeneous (e.g. in pyrolysis) and contaminated polymers without a pre-treatment (e.g. in gasification) can be treated in these processes [5]. Moreover, since waste plastics are valuable sources of various chemical compounds, and liquid and gas fuels, both the thermal and catalytic cracking of waste plastics are considered one of the most feasible large-scale recycling methods [4,6] to produce those compounds. Organic compounds either biodegradable or non-biodegradable lead to the energy as the output of thermochemical processes. Based on the availability of feedstocks and efficiency of converting the polymer wastes into usable energy (i.e. gaseous/liquid petroleum hydrocarbons, syngas, bio-oil, hydrogen, etc.), the type of thermochemical conversion (TCC) processes are selected [7]. Therefore, the TCC may include gasification, including the Fisher-Tropsch process, direct liquefaction/catalytic cracking, hydrothermal liquefaction, and pyrolysis, etc.

2.1. Pyrolysis Process for Polymer Waste to Fuel

This thermal process occurs in absence of oxygen and the generated gases possess higher calorific value to be alternatively used in various gas engines for electricity generation without any further treatment [4]. The bio-oil derived from condensation of pyrolytic gases possesses almost similar properties of the solid feedstocks. Moreover, it has vulnerable stability for long-term storage [8, 9] as it is intricately mixed with oxygenated compounds [10]. Besides, hydrocarbon oil is immiscible with the conventional hydrocarbon petroleum fuels, too [11]. This bio-oil can be further processed to obtain polymer derived gasoline, diesel as crude oils are refined in the refineries. If the purpose is to optimize the yield of liquid hydrocarbon products from the pyrolysis of polymer feedstocks, a lower temperature, higher heating rate and shorter gas residence time based operating process should be required. Fast pyrolysis process in a circulating fluidized bed (CFB) reactor could meet the requirement for this purpose as the parameter can be controlled there [12].

2.2. Catalytic Degradation of Waste Polymers

Catalytic materials successfully convert polyolefin into liquefied fuels. The fuels obtained by this technic are of transport fuel grade annulling further requirement of chemical processing [13] and are also eco-friendly [6]. Mostly, the Zeolite type catalysts are used with a ratio of polymer-to-catalyst as 1:1 at 573K and 773K for LDPE and HDPE polymer wastes respectively [13]. Besides, Tiwari and Ahmad [14] investigated on direct catalytic cracking (US-Y Zeolites, 250-800 K) of linear low density polyethylene (LLDPE) and observed that the maximum liquid yield (~89%) could be found for the plastic-catalyst ratio of 4:1.This process is advantageous due to lower reaction temperature, faster processing time, shorter residence timing, and lesser volume requirement of the reactors and controlling the formation of the unexpected products than those of thermal treatments without catalysts [15].

2.3. Thermo-Catalytic Cracking

The single stage high temperature pyrolysis with short residence time provides some shortcoming like phase changes of plastic polymers attributed as the sticking to the interior walls of the reactor before their decomposition temperature obtained [16]. Various research outputs demonstrated that the integration of modified fast pyrolysis proceeded by catalytic cracking can produce the upgraded petroleum hydrocarbons to be used in the internal combustion engines [17]. The overall process reactor temperature is economically lower than that of pyrolysis alone, thus less energy expense with the process. Miskolczi and Angyal [18] found that both the high density polyethylene (HDPE) and polypropylene (PP) plastic wastes could be transformed into gasoline (20%-48%) and light oil (17%-36%) by the thermo-catalytic process (ZSM-5 catalyst, 520 ^{0}C). Furthermore, Mani and Nagarajan [19] converted the waste plastic into hydrocarbon fuel and tested in a diesel engine. The brake thermal efficiency of the diesel engine varied from 14% to 30% without EGR in comparison to 13–29% with 20% EGR; therefore, showing potential of using waste plastic derived fuel in the diesel engines. Moreover, further technical steps are required to reduce the emissions and to increase the brake thermal efficiency of the diesel engines. The quality of waste plastic oil was found as better than the waste tyre pyrolysis oil and it could run the diesel engine with 100% of waste plastic derived fuel. Case study performed in Cynar plant in Western Australia [20] showed that the plant with an input capacity of 6000 tonnes/year of waste plastics may produce about 5.7 ML/year (70% EN590 diesel, 20% light oil, 10% kerosene). This can meet about one sixth of the total transport fuel demand of Canberra, Australia.

3. Australian Prospect of Waste Plastic Recovery

The report of Plastics and Chemicals Industries Association (PACIA) [21] reveals that Australian domestic consumption of type of soluble waste polymers (i.e. L/LDPE, PP, PS, EPS) into bio-solvent in the year 2010-2011 was about 545,608 tonnes, which is about 38% of total domestic plastic consumption. Only 76,473 tonnes were domestically recycled and 55,410 tonnes were exported to overseas for reprocessing. This amount was ~38.72% of all types of plastic wastes sent overseas for reprocessing. The rest of the wastes to fuel convertible plastic polymers (~75.828%) were not recycled. Those are dumped by landfilling or incineration processes. But these processes lead to severe air pollution. If that huge amount of plastic polymers is diverted from land filling, they can contribute to the recycling and energy production operations substantially. Both land filling and incineration can pollute the environment with the emission of various carcinogenic gases. Hydrogen chloride, dioxin, cadmium and fine particulate matters, toxic ash (30–40% of the initial amount) [22], etc. are the hazardous emissions caused by incineration [23].

4. Dissolving Waste Polymers into Bio-solvent

The prospect of dissolving waste plastics into bio-solvent (e.g. biodiesels from edible and non-edible feedstocks), thus using the polymer-biodiesel solutions as clean fuel in the internal combustion engines, opens up the potentiality of waste plastic disposal processes [24, 25]. Waste plastic polymers accounted about 33 M tonnes or 13% (w/w) of the municipal solid waste generated in 2011 in the U.S. A. [26]. On the other hand, total 2.27 M tonnes plastic wastes generated out of 60.87 M tonnes of total waste generated in Australia in 2008-2009 [27]. At least, few of the major thermoplastic polymer wastes can be dissolved well into a B100 biodiesel considering it as a good solvent [28]. Moreover, the dissolution behaviour of low density polyethylene, polystyrene, expanded polystyrene, etc. in biodiesel (B100) yielded promising solubility behaviour and improves the fuel quality by reducing the engine's emission products except NOx [25, 29-31]. Furthermore, brake thermal efficiency increases with the slight decrease of brake power at full load with significant reduction of brake specific fuel consumption rate.

5. Discussion and Further Work Plans

The authors have undertaken some investigations to analyze the potential of using integrated technologies to reduce the plastic wastes by converting them into clean hydrocarbon fuels. More investigations will be performed to distinguish the optimal process technology to convert the used polymers into transport grade fuel. Economic and technical features will be carried out to establish effective technologies and to make the outputs acceptable to the consumers. Based on the review of the processes, the following model (Fig. 1) will be investigated comprehensively.

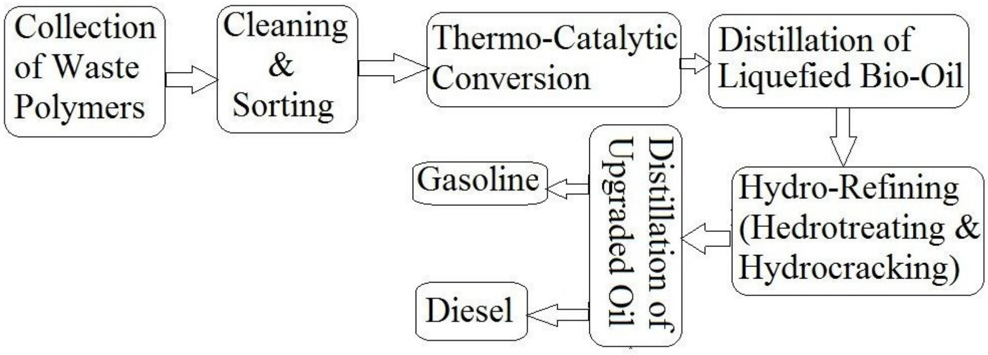

Fig. 1. Thermo-Catalytic conversion process of Waste Plastic into Fuel

6. Conclusion

Based on the reviewed articles of various applications and technologies, it can be inferred that there is potential advantage of converting waste plastics into fuel. It can effectively reduce the hazardous impact of waste accumulation on the earth. The authors have found that both thermo-catalytic process and dissolving the polymers into bio-solvents to convert the polymers into fuels have potential to be economic. It is a great challenge to determine an appropriate catalyst and bio-solvent for thermo-catalytic process and polymer dissolution process respectively. Most of the developed countries have been investigating on renewable and alternative resources of fuel or energy production processes. Hence, potential development of this process may encourage the clean fuel processing for transport sectors.

References

[1] Zhuo C, Levendis YA. Upcycling waste plastics into carbon nanomaterials: A review. *Journal of Applied Polymer Science*. 2014;**131**:1-14.

[2] Schanssema A. Resource efficiency: Best Practices for the recovery of plastics waste in Europe. PlasticsEurope; 2007.

[3] Bordynuik JW. Viable Production of Diesel From Non-Recyclable Waste Plastics. *Proceedings of the 21st Annual North American Waste-to-Energy Conference*. Florida, USA2013.

[4] Al-Salem SM, Lettieri P, Baeyens J. Recycling and recovery routes of plastic solid waste (PSW): A review. *Waste Management*. 2009;**29**:2625-43.

[5] Scheirs J. *Polymer Recycling: Science, Technology and Applications*. First ed: Wiley-Blackwell; 1998.

[6] Artetxe M, Lopez G, Amutio M, Elordi G, Bilbao J, Olazar M. Light olefins from HDPE cracking in a two-step thermal and catalytic process. *Chemical Engineering Journal*. 2012;**207–208**:27-34.

[7] Sharmina Begum, Rasul MG, Akbar D. An Investigation on Thermo Chemical Conversions of SolidWaste for Energy Recovery. *World Academy of Science, Engineering and Technology*. 2012;**62**:624-30.

[8] Diebold JP. A Review of the Chemical and Physical Mechanisms of the Storage Stability of Fast Pyrolysis Bio-Oils. In: Czernik S, editor.: National Renewable Energy Laboratory (NREL); 2000.

[9] Oasmaa A, Elliott DC. Stability of fast pyrolysis bio-oils and upgraded products. *The International Conference on thermochemical conversion Science (tcbiomass2013)*. Chicago, USA: VTT Technical Research Centre of Finland; 2013.

[10] Oasmaa A, Kuoppala E. Fast Pyrolysis of Forestry Residue. 3. Storage Stability of Liquid Fuel. *Energy & Fuels*. 2003;**17**:1075-84.

[11] Bridgewater AV. Biomass Pyrolysis. International Energy Agency Bioenergy; 2007.

[12] Van de Velden M, Baeyens J., Boukis I. Operating Parameters for the Circulating Fluidized Bed (CFB) Pyrolysis of Biomass. *Proceedings of European Congress of Chemical Engineering (ECCE-6)*. Copenhagen, Denmark2007

[13] Manos G. Catalytic Degradation of Plastic Waste to Fuel over Microporous Materials. In: Scheirs J, Kaminsky W, editors. Feeds tock Recycling and Pyrolys is of Waste Plastics: Converting Waste Plastics into Diesel and Other Fuels: John Wiley & Sons Ltd; 2006.

[14] Tiwari DC, Ahmad E, Singh KKK. Catalytic degradation of waste plastic into fuel range hydrocarbons. *International Journal of Chemical Research*. 2009;**1**:31-6.

[15] Aguado J, Serrano DP, Escola JM. Catalytic Upgrading of Plastic Wastes. In: Scheirs J, Kaminsky W, editors. Feeds tock Recycling and Pyrolys is of Waste Plastics: Converting Waste Plastics into Diesel and Other Fuels: John Wiley & Sons Ltd.; 2006.

[16] Della Zassa M, Favero M, Canu P. Two-steps selective thermal depolymerization of polyethylene. 1: Feasibility and effect of devolatilization heating policy. *Journal of Analytical and Applied Pyrolysis*. 2010;**87**:248-55.

[17] Jones SB, Male JL. Production of Gasoline and Diesel from Biomass via Fast Pyrolysis, Hydrotreating and Hydrocracking: 2011 State of Technology and Projections to 2017. U.S. Department of Energy; 2012.

[18] Miskolczi N, Angyal A, Bartha L, Valkai I. Fuels by pyrolysis of waste plastics from agricultural and packaging sectors in a pilot scale reactor. *Fuel Processing Technology*. 2009;**90**:1032-40.

[19] Mani M, Nagarajan G, Sampath S. An experimental investigation on a DI diesel engine using waste plastic oil with exhaust gas recirculation. *Fuel*. 2010;**89**:1826-32.

[20] Ricardo-AEA/R/ED58135. Case Study 3: Cynar Plastics to Diesel. *Zero Waste South Australia*2013.

[21] A'Vard D, O'Farrell K. 2011–12 National Plastics Recycling Survey. Plastics and Chemicals Industries Association (PACIA); 2013.

[22] Voudrislis N. The problem of wastes and its solutions. Soufli, Greece: Center of Environmental Education; 1998.

[23] Holton C. Dissolving the plastics problem,. *Environmental Health Perspectives*. 1997;**105**:388-90.

[24] Zhang Y, Mallapragada SK, Narasimhan B. Dissolution of Waste Plastics in Biodiesel. *Polymer Engineering & Science*. 2009;**50**:863-70.

[25] Kuzhiyil N, Kong S-C. Energy Recovery from Waste Plastics by Using Blends of Biodiesel and Polystyrene in Diesel Engines. *Energy & Fuels*. 2009;**23**:3246-53.

[26] EPA. Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2011. United States Environmental Protection Agency: Office of Solid Waste (5306P); 2013. p. 1-169.

[27] Smith K, O'Farrell K, Brindly F. Waste and recycling in Australia 2011—Incorporating a revised method for compiling waste and recycling data. Hyder Consulting Pty Ltd (ABN 76 104 485 289); 2012. p. 1-203.

[28] Gonzalez YM, de Caro P, Thiebaud-Roux S, Lacaze-Dufaure C. Fatty Acid Methyl Esters as Biosolvents of Epoxy Resins: A Physicochemical Study. *Journal of Solution Chemistry*. 2007;**36**:437-46.

[29] Salehpour S, Dub´e MA. Biodiesel: a green polymerization solvent. *The Royal Society of Chemistry*. 2008;**10**:321-6.

[30] Zhang Y, Mallapragada SK, Narasimhan B. Dissolution of Styrene–Butadiene Block Copolymers in Biodiesel. *Journal ofAppliedPolymer Science*. 2010;**118**:1859-66.

[31] Mohammadi P, Nikbakht AM, Tabatabaei M, Farhadi K. A Novel Diesel Fuel Additive to Improve Fuel Properties and to Reduce Emissions. *International Journal of Automotive Engineering*. 2012;**2**:156-62.