Review of Conversion Technologies of Waste Poly Ethylene Terephthalate (PET) Into Fuel

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***Abstract*—** PET (Poly Ethylene Terephthalate) is a polymer that is used on a wide scale for a number of domestic and industrial applications. Since nearly all fast-moving consumer products are sold in PET bottles or bins, waste PET has become a solid waste as well as an environmental pollutant as a consequence of increased use. This paper provides an overview of the current state of science and technology for transforming waste PET into usable energy outputs. Although it is possible to recycle PET and use it to make new goods, this is not achieved effectively, particularly in developing countries. In these nations, the most popular ways of coping with waste PET are landfill and incineration. Since PET is not biodegradable, using it for land fill may have serious environmental consequences. Incineration is therefore not a feasible choice since it releases greenhouse emissions and poisonous gases into the environment. According to current studies, various technologies such as aminolysis of waste PET and glycolysis of waste PET are available to produce useful production from PET waste. However, turning waste PET into liquid or gaseous fuel is a more sustainable way to cope with waste PET. PET waste may be turned into fuel using methods such as pyrolysis and gasification. However, the majority of the study results have not been broadly applied on a large scale. As a result, the aim of this paper is to expand on some current research results in order to recognize a better strategy with future research potential for converting waste PET into useful energy.

***Keywords*—** *Poly Ethylene Terephthalate (PET), Solid Waste, Aminolysis, Glycolysis, Fuel From PET Waste, Useful Energy*

I. INTRODUCTION

During the last few decades, the technology has developed by leaps and bounds, and plastics have replaced most of the materials in household and engineering applications. Plastics have become an essential component of almost every product from simple toys to synthetic body parts. The main reasons for this revolution are, possibility of plastic production in large quantities with the expanded production of fossil fuels and their availability of wide range of properties. Poly Ethylene Terephthalate (PET) is one such plastic material which is utilized in a variety of domestic and industrial applications. Polyethylene Terephthalate (PET) is a polymer, which is produced by condensation polymerization of Terephthalic acid and Ethylene glycol. In the industrial scale, PET is usually synthesized using ester-exchange method where, Dimethyl terephthalate is reacted with Ethylene glycol. Figure 1 illustrates the repeating unit of PET polymer [1].

The exact properties of PET depend on various factors such as molecular weight, molecular structure, presence of impurities and other factors. PET can be classified into several categories based on physical properties.

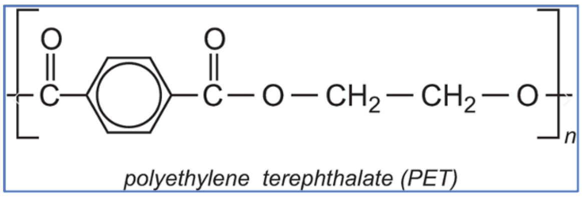

Figure 1: Repeating unit of PET [1]

As such, PET can be classified as low-viscosity PET and high-viscosity PET based on viscosity. Low-viscosity PET is used in various products like apparel fiber, bottles and photographic films and high-viscosity PET is used in seat belts and tire-cords. PET is a thermoplastic material and can be used in the form of fiber, sheet or film. Polyethylene Terephthalate has a variety of applications including synthetic fiber, beverage bottles, food packaging, containers for toiletries, cosmetics and pharmaceuticals, molding resins, X-ray and other photographic films, magnetic tape, electrical insulation and printing sheets. Among those, the most common applications are utilization of PET as a packaging material, and as disposable water bottles [2].

In consequence of the main source of PET is crude oil, the extensive consumption of this type of plastic has contributed the rapid diminishing of non-conventional energy sources in the world. It has been estimated that, 25% of PET produced every year all over the world, are dumped after consumption in various ways. These actual quantities are in millions of tons annually [3]. Therefore, it is true that, huge energy content in the form of crude oil is wasted annually that is used to make plastics in the form of PET. This is why the techniques to recover this waste PET as a useful energy output becomes so valuable. In other words, the depleting rate of non-renewable energy sources like fossil fuels can be reduced into certain extent with these kinds of approaches of waste energy recovery. Approximately 3 million tons of PET are produced annually to make disposable bottles [4]. Those water bottles are usually designed to be disposed after using once. Therefore, used PET bottles are a significant component in municipal waste as well as can be observed in any waste collection bin as a common type of garbage. Although it is possible to recycle PET and use them to produce new products, recycling of PET is not a viable solution especially for developing countries because it a very expensive process [4]. The most common methods of dealing with waste PET bottles in developing countries are using them for landfilling and incineration [4]. Using disposed PET bottles for landfilling can cause severe environmental issues because they are not bio-degradable. Incineration is also not a suitable solution because, it will cause emissions of greenhouse gases like CO2 and toxic gases like SO2. In addition, incineration of PET will produce very hard and solid complex substances of Terephthalic acid and benzoic acid, which are not bio- degradable [4]. Therefore, it is necessary to implement more sustainable solutions in order to deal with PET waste which will be suitable for developing countries like Sri Lanka.

In existing literature, many researches are carried out to make use of waste PET in alternative ways rather than disposing them to environment. The Aminolysis of PET waste can be used as a corrosion inhibitor in Carbon steel for hydrochloric acid (HCl). This has been experimentally shown by recycling PET waste using Mono ethanol amine (MEA), sodium acetate and HCl [5]. The results were found using weight loss, open circuit potential and potentio-dynamic polarization measurements [5]. According to those results, it has been found that PHETA [poly (bis (2-hydroxy ethylene) terephthalamide] is a good inhibitor for Carbon Steel in HCl medium and the efficiency of the inhibitor will be increased with the increasing concentration of PHETA [5]. However, the efficiency of the inhibitor decreases with the increment of temperature and that concludes the protective film created by these compounds in Carbon Steel is less stable at higher temperatures [5].

PET waste dumped in soil can be pretreated with ultra violet rays (UV), heat, nitric acid and then introduced with micro-organism named Pseudomonas sp [6]. Such treated samples displayed significant changes on the surfaces morphology of PET observed using an SEM microscope [6]. The Pseudomonas sp shows to have the ability to adsorb over the PET surface and accelerate the PET degradation process [6]. Experimental analysis carried out for a period of one month, revealed that, using micro-organisms to accelerate the degradation of PET can be used as an effective method to minimize the environmental pollution caused by waste PET landfilling [6], [7].

PET waste can be used to produce Polyester Polyol for coating applications for Mild Steel. In this process, initially the PET was put under the glycolysis process using poly propylene glycol. Secondary reaction was the trans-esterification process carried out using Castor or Jatropha oil [8]. Then the produced polyester polyol combined with Melamine Formaldehyde is coated on mild steel. The research pointed out that the coating properties were depended on the amount of PET used for glycolysis and the type of oil used for the trans- esterification [8]. When the percentage of PET was increased, properties of mild steel such as, corrosion resistance, MEK double rub resistance, pencil hardness, and solvent and chemical resistance were increased. Coating system which was based on Castor oil having a 10% PET showed the best performance [8].

Waste PET is possible to use as an aggregate in Concrete too. According to the past research, three aggregate types prepared from PET waste were used which are namely the coarse flakes (PC), fine fraction (PF) and the plastic pellets (PP) [9]. The result showed that the development of compressive strength of concrete containing all types of PET aggregates was similar to conventional concrete [9]. However, when the early compressive strength gain (0 to 7 days) was compared to the compressive strength determined after 91 days of curing, the compressive strength in concrete containing PET aggregates was higher than that of the conventional concrete [9]. Furthermore, the incorporation of PET aggregate in concrete increased its' toughness behavior [9]. For a given amount of PET addition, the toughness behavior was increased in the manner of PC > PF > PP respectively, which indicates that the addition of large flake PET aggregates can have more effect on the improvement of the toughness behavior of resulting concrete [9].

Two novel additive materials, namely Thin Liquid Polyol PET (TLPP) and Viscous Polyol PET (VPP) have been derived chemically from PET bottle wastes and used as additive within the asphalt in order to use as a roadway pavement construction material. According to the results of the research executed with TLPP and VPP modified asphalts, they can be recommended to use in regions with low temperatures and high humidity as a construction material to improve the roadway performance [10].

Even though existing literature suggests several alternative approaches and different techniques of converting waste PET into some kind of useful output, almost all of those methods have not been able to make a significant effect towards the non-renewable energy wastage happens in the energy lifecycle in the world. However, it can be observed in the existing literature that, a more sustainable solution to deal with PET waste is to convert waste PET into liquid or gaseous fuel. This is also useful in aspects of sustainable energy, because this fuel will act as an alternative for petroleum fuel. Methods like pyrolysis and gasification can be used to produce fuel from PET waste. Therefore, this research paper will converge and summarize the most recent existing research outcomes regarding the waste PET conversion into useful fuels.

II. REVIEW AND DISCUSSION

Various research studies can be found regarding conversion of PET into liquid fuel and useful energy. In one of such experiment, pellets of PET obtained from waste water bottles had been mixed with catalysts with a catalyst to sample ratio of 2, and heated at 405 0C for 20 minutes to convert PET into liquid fuels through catalytic thermal conversion [4]. According to past research $Ca(OH)_2$, $Ni(OH)_2$ and Fe_2O_3 can be used as catalysts for this conversion [4]. The resulting product had consisted of 14.25% liquid fuel, 12.5% volatile gases, 51.5% solid residue and 21.75% water [4]. The yield of fuel from pure PET is low due to high Oxygen percentage in PET [4]. However, it has been experimentally shown that the yield of fuel can be increased by mixing PET with other plastics like LDPE. The liquid fuel obtained from this experiment had been a highly flammable, yellowish liquid with a density of 0.9 g/ml and a boiling point of 65.96 0C, and the solid residue had been an ash-coloured crystalline powder [4]. The fuel samples obtained in this experiment had been analyzed using gas chromatograph/mass spectrophotometer (GC/MS). According to the obtained results, the liquid fuel consisted of saturated and unsaturated hydrocarbons containing 6 to 27 Carbon atoms as well as, some aromatic compounds like Benzene, Benzene ethanamine etc. [4]. The GC/MS chromatogram and differential scanning calorimeter (DSC) curve which were obtained for this fuel in the cited research experiment have been given by figure 2 and figure 3 respectively [4].

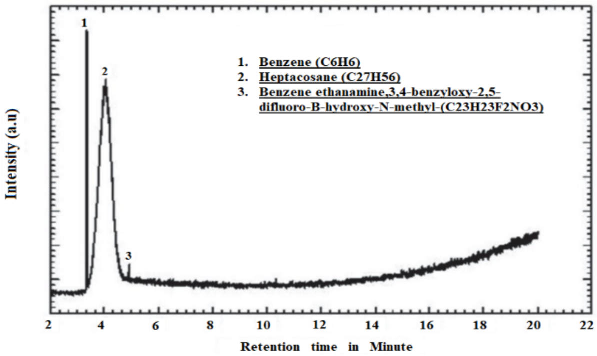

Figure 2: GC/MS chromatogram for fuel produced using PET [4]

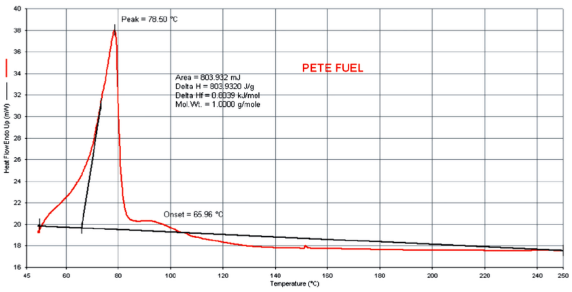

Figure 3: Differential Scanning Calorimeter DSC curve for liquid fuel produced using PET [4]

In addition, several other experiments have been conducted about the thermal degradation of mixtures of PET and LDPE. In one of such experiments, a mixture consisting of 10 grams of PET obtained from disposed water bottles and 50 grams in LDPE obtained from grocery bags had been heated in an atmospheric Pyrex glass reactor of laboratory scale at a temperature range between 250 0C- 400 0C [11]. According to the results of this experiment, the product had consisted of 53.5% liquid, 11.83% of gas and 34.67% of wax, and the product liquid fuel had been a light-yellow colored liquid with a density of 0.76 g/ml [11]. When comparing with the results of the previous experiment, it is observed that the fuel yield is much higher in the mixture of PET and LDPE than pure PET [11]. After removing wax by means of filtration, liquid and gas streams had been collected separately. The product fuel had mainly consisted of light hydro carbons, but it had also contained various other organic compounds containing up to 22 Carbon atoms. The compounds which were available in significant quantities in resultant fuel were propane, butane, pentane, hexane, heptane, octane, 2-pentene, benzene, cyclo-pentane, 3-methyl hexane and hydro carbons which contained up to 20 carbon atoms [11]. In addition, the resulting fuel had also contained Oxygen containing organic compounds like alcohols and carboxylic acids, due to the presence of ester group in Poly Ethylene Terephthalate. The GC/MS chromatogram for the resulting fuel mixture is given by figure 4.

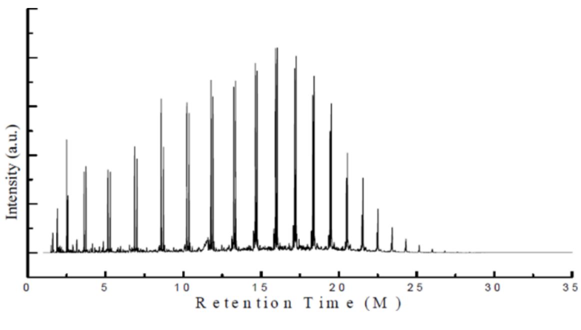

Figure 4: The GC/MS chromatogram of the fuel mixture obtained through thermal degradation of PET and LDPE mixture [11]

Another concept where experiments have been conducted recently based on the useful energy from waste PET is the use of waste plastics as modifiers of the thermoplasticity of coal. Two bituminous coals of different ranks, type W and SF, and six types of plastics, HDPE, LDPE, PET, PP, PS and ABS had been used in that experiment [12]. Each plastic waste had been cryogenically ground to a particle size of less than 10 mm and mixed with bituminous coal with compositions ranging from 2.5% to 10%, and the blended coal had been tested using Gieseler Plastometer Test and Thermogravimetric Analysis [12]. According to the results of this experiment, the addition of PET to coal greatly reduced coal fluidity [12]. Since a certain amount of fluidity is required in coal to be used in the production of coke, it is recommended to use PET for combustion or gasification and also in carbon material manufacturing rather than using as an additive in coal because during combustion, power plant authorities prefer a reduction or destruction of caking ability of coal. However, PET can be used as an additive to coal, if it is added in very small quantities [12].

Gasification also has been considered as a method of producing fuel from waste PET. Gasification is considered as an effective sustainable waste management technique, because it can contribute to reduce environmental hazards and land filling as well as maximize energy recovery. A simulation of the gasification process of blends of PET and Polyethylene (PE) had been done using Aspen Plus process simulation software [13]. The resulting gas had been analyzed by measuring product gas composition, gas temperature, lower heating value, gas yield and conversion with respect to CO and H2 [13]. According to the results of the simulation, higher PET percentages have given higher Carbon conversion efficiency, due to high Oxygen content in PET. However, Hydrogen conversion has not changed with the increment of PET percentage in the mixture [13]. Therefore, Hydrogen to Carbon Monoxide ratio in product synthesis gas had been lower for PET and PE mixture. Further simulation results revealed that the Hydrogen to Carbon Monoxide ratio was slightly higher in PET and PE mixture than that for pure PET [13]. Therefore, gasification of PET is recommended only in occasions where a low Hydrogen to Carbon Monoxide ratio is required, like large scale methanol production. However, since this is only a simulation, more experiments will be required to be conducted in order to validate this phenomenon.

Pyrolysis is another method which can be used to convert plastics into liquid hydro carbons. However, in order to obtain a high yield of fuel, it is recommended to use low density plastics consisting of only Carbon and Hydrogen. PET has a comparatively high density due to the presence of Oxygen atoms, and pyrolysis of PET will mainly give a mixture of Carbon Dioxide and Carbon Monoxide due to the higher content of Oxygen present, with a significant amount of char [14]. Therefore, pyrolysis is not considered as an effective method to convert PET into liquid fuel [14].

CONCLUSION

The aim of this research analysis study was to look at a more effective approach to the evolving energy and environmental problems associated with waste PET. Based on current literature, it was discovered that waste PET can be transformed to corrosion inhibitors and coating applications in metals during this research. Furthermore, it was discovered that waste PET decay in soil can be increased in the presence of specific microorganisms, which is a favorable fact for landfilling. Furthermore, it was investigated if waste PET could be used as an admixture in both concrete and asphalt for building purposes, as well as a road paving material. However, of all possible alternatives, converting waste PET into usable fuel or resources was described as a more sustainable option. During this research, three significant techniques for transforming waste PET into liquid hydrocarbon fuels were discovered. Catalytic thermal transfer, gasification, and pyrolysis are the three processes. According to previous research, pyrolysis is not an appropriate tool for converting waste PET into liquid fuels. Meanwhile, in both catalytic thermal conversion and gasification, PET is turned into gasoline by merely heating the PET polymer. As a consequence, these systems are easy to incorporate and have a smaller capital expense. However, both of these existing experiments are on a lab scale, and it is yet to be decided if the same productivity of lab scale plants can be accomplished on an industrial scale. The popular issue in all of these strategies is that the fuel yield is poor due to the large quantities of solid residue formed as a result of the high oxygen content in Poly Ethylene Terephthalate. It has not been determined if this strong residue will be used to manufacture some valuable commodity or blended with existing gasoline. As a result of this report, potential research areas for scaling up these innovations to an industrial scale and seeking viable alternatives to increase conversion efficiencies were identified. As a consequence, this study may be generalized to perform potential studies focused on these research concerns.

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