Review Paper on Plastic Waste Management for Smart City

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***Abstract*—** Plastic solid waste (PSW) presents challenges and opportunities to societies regardless of their sustainability awareness and technological advances. In this paper, recent progress in the recycling and recovery of PSW is reviewed. A special emphasis is paid on waste generated from polyolefinic sources, which makes up a great percentage of our daily single-life cycle plastic products. The four routes of PSW treatment are detailed and discussed covering primary (re-extrusion), secondary (mechanical), tertiary (chemical) and quaternary (energy recovery) schemes and technologies. Primary recycling, which involves the re-introduction of clean scrap of single polymer to the extrusion cycle in order to produce products of the similar material, is commonly applied in the processing line itself but rarely applied among recyclers, as recycling materials rarely possess the required quality. The various waste products, consisting of either end-of-life or production (scrap) waste, are the feedstock of secondary techniques, thereby generally reduced in size to a more desirable shape and form, such as pellets, flakes or powders, depending on the source, shape and usability. Tertiary treatment schemes have contributed greatly to the recycling status of PSW in recent years. Advanced thermo-chemical treatment methods cover a wide range of technologies and produce either fuels or petrochemical feedstock. Nowadays, non-catalytic thermal cracking (thermolysis) is receiving renewed attention, due to the fact of added value on a crude oil barrel and its very valuable yielded products. But a fact remains that advanced thermo-chemical recycling of PSW (namely polyolefins) still lacks the proper design and kinetic background to target certain desired products and/or chemicals. Energy recovery was found to be an attainable solution to PSW in general and municipal solid waste (MSW) in particular. The amount of energy produced in kilns and reactors applied in this route is sufficiently investigated up to the point of operation, but not in terms of integration with either petrochemical or converting plants. Although primary and secondary recycling schemes are well established and widely applied, it is concluded that many of the PSW tertiary and quaternary treatment schemes appear to be robust and worthy of additional investigation.

Keywords*— *landfills, incineration, mechanical recycling, chemical recycling, plastic waste

I. INTRODUCTION

Plastics have become an inseparable and integral part of our lives. The amount of plastics consumed annually has been growing steadily. Its low density, strength, userfriendly designs, fabrication capabilities, long life, light weight, and low cost are the factors behind such phenomenal growth. Plastics have been used in packaging, automotive and industrial applications, medical delivery systems, artificial implants, other healthcare applications, water desalination, land/soil conservation, flood prevention, preservation and distribution of food, housing, communication materials, security systems, and other uses. With such large and varying applications, plastics contribute to an ever increasing volume in the solid waste stream. In the year 1996, plastics amounted to about 12% of MSW, by weight, in United States (Franklin Associates Ltd.,1998). The waste plastics collected from the solid wastes stream is a contaminated, assorted mixture of plastics. This makes the identification, segregation, and purification of the various types of plastics very challenging. In the plastics waste stream, polyethylene forms the largest fraction, which is followed by PET. Lesser amounts of other plastics can also be found in the plastics waste stream.

Plastics are man-made organic materials that are produced from oil and natural gas as raw materials. Plastics consist of large molecules (macromolecules), the building blocks of all materials. The molecular weights of plastics may vary from about 20, 000 to 100,000 mg/L. Plastics can be regarded as long chains of beads in which the so-called monomers such as ethylene, propylene, styrene and vinyl chloride are linked together to form a chain called a polymer. Polymers such as polyethylene (PE), polystyrene (PS) and polyvinyl chloride (PVC) are the end products of the process of polymerization, in which the monomers are joined together. In many cases only one type of monomer is used to make the material, sometimes two or more.

A wide range of products can be made by melting the basic plastic material in the form of pellets or powder. Plastics can be either thermoplastics or thermosets. Materials that repeatedly soften on heating and harden on cooling are known as thermoplastics. They can be melted down and made into new plastic end products. Thermoplastics are similar to paraffin wax. They are dense and hard at room temperature, become soft and mouldable when heated, dense and hard again and retain new shapes when cooled. This process can be repeated numerous times and the chemical characteristics of the material do not change. In Europe, over 80% of the plastics produced are thermoplastics (Warmer Fact Sheet, 1992).

Thermosets, on the other hand are not suitable for repeated heat treatments because of their complex molecular structures. The structure of thermosetting materials resembles a kind of thinly meshed network that is formed during the initial production phase.

Such materials cannot be reprocessed into new products unlike thermoplastics. Thermosets are widely used in electronics and automotive products.

The properties of plastics can be modified by a number of substances known as additives

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A) Benefits/advantages of plastics

The growth in the use of plastic is due to its beneficial properties, which include:

Extreme versatility and ability to be tailored to meet specific technical needs., Lighter weight than competing materials reducing fuel consumption during transportation. Good safety and hygiene properties for food packaging. Durability and longevity. Resistance to chemicals, water and impact. Excellent thermal and electrical insulation properties. Comparatively lesser production cost. Unique ability to combine with other materials like aluminum foil, paper, adhesives. Far superior aesthetic appeal. Material of choice – human life style and plastic are inseparable. Intelligent features, smart materials and smart systems.

Today, you can hardly look around you and not spot some item that is made entirely from plastic or has some plastic ingredient. This only proves that from its inception up to now plastic has managed to become popular building material of millions of useful items, but it is not perfect. Plastic has several disadvantages that prevent it from becoming universal building block of modern human civilization, and because of that many governments strictly control its use and create complex law that govern its creation, recycling and environmental impact of waste plastic and chemicals that are used in its creation.

B)Here are some of the biggest disadvantages of plastic:

Durability – Plastic is light, moldable, sturdy, and can have countless forms, but one of the most known features is its durability. Plastic is artificially created polymer compound which can survive many centuries before nature is able to degrade it (some degrade into basic ingredients and some only divide into very small pieces). This troublesome ability of plastic doesn't have great immediate impact on our environment, but its continuous dumping into seas and land will eventually create problems for future generations. Even with all this durability, plastic products are not indestructible and it cannot be used as a basic building block for everything we need.

Environmental Harm – Ever increasing plastic production since 1950s managed to saturate world with waste plastic product that can cause big effects on our environment. Decomposing of plastic product can last from 400 to 1000 years with newer "degradable" compounds, but before that degradation can happen waste plastic will continue to clog our waterways, oceans, forests, and other natural habitats that are filled with animals who mistake dangerous plastic for food. Chemical dangers are also high, because both creation and recycling of plastic produce toxic materials of many kinds.

Chemical Risk – Not only that creation and recycling of plastic can cause serious environmental risk, but some of the additives that are infused in plastic can cause permanent harm to our metabolism. Chemicals such as phthalates and BPA are widely used as an additive that prevents degrading of plastic structure, but they also interfere with our natural hormone levels which can cause serious problems to both males and females (lower testosterone levels in men, and premature girl puberty).

Choking Hazard – Plastic is one of the most popular building materials for small items. This is most evident in toy industry, where vast majority of children toys is manufactured with plastic. These toys and small plastic objects of many uses can easily get into children's hands (especially babies and toddlers) that unknowingly put them in their mouth. To prevent these serious accidents, governments have implemented detailed set of rules which force manufacturers to clearly label their plastic products and warn users of the possible chocking potential. Another problematic plastic product that can cause serious injuries or death are plastic bags (grocery or trash bags)who can sometimes end up wrapped around children faces, disrupting their breathing.

C)Hazardous effects of Plastics

Polluting Substances

In terms of environmental and health effects it is important to differentiate between the various types of plastics. Most plastics are considered nontoxic (PVC is an important exception). Polyethylene (PE) and polypropylene (PP), for example, are inert materials (Mewis, 1983), but it should be realized that plastics are not completely stable. Under the influence of light, heat or mechanical pressure they can decompose and release hazardous substances. For example, the monomers from which polymers are made may be released and may affect human health. Both styrene (which is used to make polystyrene, PS) and vinyl chloride (used to make PVC) are known to be toxic, and ethylene and propylene may also cause problems (Beumer, 1991).

The environmental effects of plastics also differ according to the type and quantity of additives that have been used. Some flame retardants may pollute the environment (e.g. bromine emissions) .Pigments or colorants may contain heavy metals that are highly toxic to humans, such as chromium (Cr), copper (Cu), cobalt (Co), selenium (Se), lead (Pb) and cadmium (Cd) are often used to produce brightly colored plastics. Cadmium is used in red, yellow and orange pigments. In most industrialized countries these pigments have been banned by law. The additives used as heat stabilizers (i.e. chemical compounds that raise the temperature at which decomposition occurs), frequently contain heavy metals such as barium (Ba), tin (Sn), lead and cadmium, sometimes in combination (Nagelhout, 1989).

II POPULAR WAYS TO DEAL WITH WASTE

A)Landfills and Incineration

With so much plastic waste being generated worldwide on a daily basis, where does it all go? Waste is managed primarily in one of the following ways. Incineration deals with waste simply by hauling large sums of trash into management plants, and reducing it to carbon via combustion. A large portion of the waste we generate is also buried under ground, in landfills, and some waste often ends up littering streets and countrysides via open dumping (quite unfortunately). Although these methods are often utilized, there are nonetheless negative impacts associated with them. Most of the waste we generate is disposed of via landfilling or incineration. It is often difficult to find adequate places to build landfills, and incineration releases a large amount of greenhouse gases into the atmosphere. Due to these issues both methods negatively impact the environment(Pinto, et al., 2008). Exactly how do these methods compare, which is more effective, and what are the consequences?

In a landfill, as waste breaks down methane is generated. This gas can be recovered and used to generate electricity. In this light, landfilling is an effective method of dealing with portions of MSW, however plastic waste creates an eternal problem. Plastic products synthesized from petroleum are not biodegradable. For this reason, plastic waste remains in landfills, without breaking down or changing composition. The buildup of plastic waste in landfills is simply not sustainable(Gheewala and Liamsanguan, 2008).

When incinerated, plastic releases high amounts of fossil carbon into the atmosphere as CO2. Methods of plastic separation, prior to incineration, can help reduce the amount of greenhouse gases released into the atmosphere, however that is easier said than done. Many factors come into play in managing waste, but improving the efficiency of plastic separation could cause less environmental harm. Incineration requires a large amount of energy, but some can be recovered in the process. Although removing plastic waste from the equation reduces greenhouse gas emissions, much less energy can be recovered from incineration in the absence of plastics. (Gheewala and Liamsanguan, 2008) The idea behind waste management is to recover as much as possible, be that energy, or useable resources. Thus, many factors come into play (Gheewala and Liamsanguan, 2008).

B) Plastics waste utilization processes

Mixing with concrete

here the utilization of thermosetting plastic as an admixture in the mix proportion of lightweight concrete. Since this type of plastic cannot be melted in the recycling process, its waste is expected to be more valuable by using as an admixture for the production of non-structural lightweight concrete. Experimental tests for the variation of mix proportion were carried out to determine the suitable proportion to achieve the required properties of lightweight concrete, which are: low dry density and acceptable compressive strength. The mix design in this research is the proportion of plastic, sand, water–cement ratio, aluminum powder, and lignite fly ash. The experimental results show that the plastic not only leads to a low dry density concrete, but also a low strength. It was found that the ratio of cement, sand, fly ash, and plastic equal to 1.0:0.8:0.3:0.9 is an appropriate mix proportion. The results of compressive strength and dry density are 4.14 N/mm2 and 1395 kg/m3, respectively. This type of concrete meets most of the requirements for nonload-bearing lightweight concrete according to ASTM C129 Type II standard.

C) Plastics waste recycling processes

Plastics recycling or reprocessing is usually referred to as the process by which plastic waste material that would otherwise become solid waste are collected, separated, processed and returned to use (Lardinois and Van de Klundert, 1995). Developing an efficient and cost-effective method for recycling waste plastics that have served their intended purpose, retrieving them from the waste stream and getting them back into the manufacturing process requires collection, sorting and cleaning and finally reclamation. For homogeneous plastic waste streams recycling by mechanical (or physical) methods is the economically preferred recovery option. Heterogeneous plastic waste streams however are more efficiently treated or handled by chemical and thermal processes, for recovery of basic chemicals and /or energy (Gaiker-IVL and KTH, 2005). These processes are briefly discussed below.

1)Mechanical Recycling

Mechanical recycling is the material reprocessing of waste plastics by physical means into plastics products. The sorted plastics are cleaned and processed directly into end products or into flakes or pellets of consistent quality acceptable to manufactures. The steps taken to recycle post-consumer plastics may vary from operation to operation, but typically involve inspection for removal of contaminants or further sorting, grinding, washing and drying and conversion into either flakes or pellets.

Pellets are made by melting down the dry plastic flakes and then extruding it into thin strands that are chopped into small, uniform pieces. The molten plastic is forced through a fine screen (filter) to remove any contaminants that may have eluded the washing cycle. The strands are cooled, chopped into pellets and stored for sale and shipment. Different plastics may also under different reforming conditions such as different processing temperatures, the use of vacuum stripping, or other procedures that could influence contaminant levels. During the grinding or melting phases, the reprocessed material may be blended with virgin polymer or compounded with additives.

2)Monomerization

From PET bottles to PET bottles While PET bottles can be recycled to make textiles and sheeting, they cannot be used to make PET drinks bottles. This is because used PET bottles are unsuitable for use as raw materials for soft drink, alcohol or soy sauce bottles for reasons of hygiene and smell. However, converting PET bottles back to an earlier state of processing is a more economic use of resources than making PET resin from scratch out of petroleum and naphtha. A "bottle-to-bottle" scheme to make recycled resin equivalent to newly made resin suitable for drinks bottles started in 2003 on this basis. The method chemically decomposes the used PET bottles into their component monomers (depolymerization), and they are made into new PET bottles from this stage.

Tenjin Ltd. already uses its own proprietary decomposition method, combining ethylene glycol (EG) and methanol to break waste PET resin down into DMT (dimethyl terephthalate) to turn it the raw material used to make textiles and film. This technique was improved upon to break PET bottles down further from DMT to PTA (purified terephtalic acid) to make PET resin, and Tenjin Fiber Ltd. commenced operation of a facility with the capacity to process around 62,000 tons a year in 2003. The resin produced was judged suitable for use in food containers by the Japanese Food Safety Commission in 2004, and bottle-to-bottle production started in April with the approval of the Ministry of Health, Labor and Welfare.

3)Blast furnace feedstock recycling

Plastics used as a reducing agent At steel mills, iron ore, coke and auxiliary raw materials are fed into a blast furnace and the iron ore melted to produce pig iron. Coke is used as fuel to elevate the temperature in the furnace, and also acts as a reducing agent by removing the oxygen from iron oxide, one of the main constituents of iron ore. As plastics are made from petroleum and natural gas, their main constituents are carbon and hydrogen. This means that it should be possible to devise a means of using them instead of coke as a reducing agent in the blast furnace process.

The process by which plastics are used as a reducing agent is as follows. Plastic waste collected from factories and homes is cleansed of non-combustible matter and other impurities such as metals, then finely pulverized and packed to reduce its volume. Plastics that do not contain PVC are granulated, then fed into the blast furnace with coke. Plastics that do contain PVC are fed into the blast furnace after first separating the hydrogen chloride at a high temperature of around 350℃ in the absence of oxygen, as the emission of hydrogen chloride can damage a furnace. The hydrogen chloride thus extracted is recovered as hydrochloric acid and put to other uses, such as acid scrubbing lines for hot rolling at steel mills.

4)Coke oven chemical feedstock recycling

Plastic waste reused in coke ovens Coke is made by baking coal, and the process also generates volatile compounds which produce hydrocarbon oil and coke oven gas. However, coke, hydrocarbon oil and coke oven gas can also be produced from plastic waste. Nippon Steel Corporation has developed facilities at most of its steel mills to use plastic waste as chemical feedstock and fuel, and it is now in use in its Nagoya, Kimitsu, Muroran and Yawata sites.

At these plants, plastic waste collected from households is first shredded and impurities such as iron are removed. PVC is removed before the plastics are heated to 100℃ and granulated, then mixed with coal and fed into the carbonization chamber of a coke oven.

The carbonization chamber has combustion chambers on both sides which heat the content indirectly. The waste plastic does not combust inside the chamber due to lack of oxygen, but it is instead cracked thermally at a high temperature to produce coke for use as the reducing agent in coke ovens, hydrocarbon oil which is used as chemical feedstock, and coke oven gas which is used to generate electricity.

5)Gasification

Plastics are converted to gas for use as a raw material in the chemical industryPlastics are composed mainly of carbon and hydrogen and therefore normally produce carbon dioxide and water when combusted. The gasification process involves heating plastics and adding a supply of oxygen and steam. The supply of oxygen is limited, which means that much of the plastics turn into hydrocarbon, carbon monoxide and water. Sand heated to 600-800℃ is circulated inside a first-stage low-temperature gasification furnace. Plastics introduced into the furnace break down on contact with the sand to form hydrocarbon, carbon monoxide, hydrogen and char. If the plastics contain chlorine, they produce hydrogen chloride. If plastic products contain metal or glass, these are recovered as non-combustible matter.

6)Liquefaction

Waste plastic converted back to oil As plastics are produced from petroleum, it should be possible to produce petroleum from them by reversing the process by which they are manufactured. The Plastic Waste Management Institute has established a technique to convert plastic waste back to oil following development work initiated in the late 1970s.With the assistance of a grant from the Ministry of International Trade and Industry (now the Ministry of Economy, Trade and Industry), the Plastic Waste Management Institute undertook a successful three-year project from FY 1995, called the Next-Generation Plastic Waste Liquefaction Technology Development Project, to develop a method of effectively converting plastic waste of a variety of types to oil (i.e. liquefying them). To trial the technology, the Niigata Plastic Liquefaction Center was established in Niigata City by Rekisei Kouyu Co., Ltd. to process all kinds of household plastic waste. Applying the Plastic Waste Management Institute's own findings from the above project, the center entered trial operation in December 1997 and commercial operation in May 1999. The conversion of different types of waste plastic back to oil was thus put into practical operation, but the business closed down in 2006 after issues bidding for containers under the Container and Packaging Recycling Law.

7)Thermal recycling

From waste plastic and landfill to thermal recycling Waste plastics are currently collected and processed differently by different municipalities, but the Ministry for the Environment is unifying the previously separate categories of waste into one ("burnable"), with an amendment to the Waste Disposal Law on 26 May 2005 which changes its basic policy to state that "first, emission of waste plastic should be reduced, after which recycling should be promoted; any remaining waste plastic should not go to landfill as it is suitable for use in thermal recovery". In a similar move, the Tokyo municipal area, which had since 1973 been putting household waste plastics into landfill as non-burnable garbage, set a goal in 2008 of sending zero household waste plastic to landfill and instead using it for incineration and thermal recycling by default. Many EU countries already use waste plastics for thermal recycling as part of their recycling programs. Thermal recycling encompasses liquefaction, gasification and solid fuel (RPF, etc.), which are all recognized under the Container and Packaging Recycling Law, but also waste power generation, conversion to cement kiln fuel and solid fuel made from waste (RDF). Current widely used methods of power generation from waste incineration are stoker incineration, gasification with melting furnace, and gasification with reformer furnace Gasification with melting furnace waste power generation first converts waste to gas at a high temperature, then uses the emitted pyrolysis gas and char as fuel to turn a steam turbine and generate power. This method turns the burned ash into a solid. Gasification with reformer furnace power generation subjects the waste to pyrolysis, then adds oxygen to the resulting gas, carbonized solids, tar and other substances. Gas rich in carbon monoxide and steam is recovered and used as fuel for power generation or as chemical feedstock. Any method of gasification for waste material can be used with shaft furnaces, fluidized bed furnaces or rotary kilns. Also, power can be generated not only via steam turbines, but also with high efficiency gas engines, gas turbines and fuel cells.

III. IMPORTANCE OF PLASTIC WASTE MANAGEMENT

There is only one environment and it must be treated with the respect it deserves If raw materials have already been extracted then it makes sense to use them again if possible. This means that reserves last longer into the future. Moreover, recycling of plastic waste conserves natural resources, particularly raw materials such as oil and energy. The more that is recycled, the longer will natural resources be available for future generations. It means that there is less environmental impact due to mining, quarrying, oil and gas drilling, deforestation and the likes. If there are fewer of these operations, the environment will be safe from continuous destruction and degradation.

Another positive effect of recycling on the environment is that it may reduce emissions of substances such as carbon dioxide (CO2) into the atmosphere. From 'life- cycle' analysis of reprocessed plastics and virgin plastics, it is known that the emissions of CO2, SO2, NOX (NO and NO2) are much smaller for recycled plastics compared to that for virgin materials (Lardinois and Van de Klundert, 1995). Hence the environment will be better safe from air pollution and global warming if recycling is adopted on large scales. Recycling of plastic wastes will also safe both ground and surface waters from pollution. This is because if discarded randomly, they choke gutters and even find their way into water bodies that serve as sources of drinking water for communities and towns. They also help to breed leachate that can seep into the ground thereby contaminating groundwater bodies as well.

IV CONCLUSION

The past decade has seen increased awareness of the environmental issues and general support for exploration and implementation of methods and practices to make our products and processes more environmentally benign. Consequentially, substantial progress has been made in the areas of environmental management. In the case of solid wastes including plastics, significant progress has been made in reducing waste and increasing the quantities being recycled. Chemical recycling to make monomers, in the case of nylon and polyesters, has been established and disposal of very complex and contaminated mixtures of plastics by incineration has been developed. While several new technologies have been developed, the amounts of materials being recycled appear to have reached a plateau. In the absence of additional legislative mandates, further progress in recycling of plastics might be slower, given the relatively high costs of recycling, the low cost of energy, and the low cost of land filling. Yet, with a long-term perspective, greater dedication to higher environmental quality and life cycle analysis of products, growth of plastics and its recycling could become more important in the future.

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