PROCESS ROUTES FOR EFFECTIVE DISPOSAL OF PLASTIC SOLID WASTE: A REVIEW

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ABSTRACT: Four techniques and schemes are used in plastic solid wastes (PSW) treatments, which are primary (re-extrusion), secondary (mechanical), Tertiary (chemical), and quaternary (energy recovery). Primary recycling, re-extrusion technique is usually used in the producing line itself where clean junk of single polymer is reused to obtain new products of the same material. Different waste products that are either end-of-life or junk are usually used as the primary material of secondary techniques; thus, the overall shape and form are decreased to be more likable such as granules, chips, or fine particulates relying on the origin, form, and ease of use. Recently, Tertiary treatment techniques have significant contributions to the recycling process of PSW. Advanced thermo-chemical treatment methods are the major technologies used which produce either fuel or petrochemical raw materials. A valuable PSW in both wastes generally and a municipal solid waste especially is energy recovery. Even when re-extrusion and chemical treatment techniques are more applied, it’s noticed that thermo-chemical and energy recovery treatment techniques are more powerful and worthy of being more studied.

Keywords: plastic solid waste, waste disposal, waste recycling, waste treatment

1. INTRODUCTION

Because of the wide range of using plastics in the daily lives, a large PSW amount is found in the muncipal solid wastes (MSW) final stream each year the thing that encourage more focused researchers to be held on the recycling of PSW over the last decades especially by adjusting the environmental regulations as the significant growth in the consumption, rate of waste generation and production of PSW since Plastics were first produced in an industrial scale in the 1940s. Thoroughly researches found many alternative treatment, recycling and recovery techniques for the disposal of PSW to overcome the increased cost and the lack of landfill spaces (Howard, 2002; Zia, Bhatti, & Ahmad Bhatti, 2007).

Four techniques and schemes are used in PSW treatments, which are primary (re-extrusion), secondary (mechanical), Tertiary (chemical), and quaternary (energy recovery). Each technique has the specifications that made it suitable in particular conditions.

2. REUSING, SORTING AND PRIMARY RECYCLING

2.1. Re-using and main sorting techniques benefits

Single used plastics are the major source of PSW. So, it is always preferred to be used again and recycled for reducing the energy and resources used. Recently, it is a popular thing to use plastics for multi-purposes, which helps to reduce PSW in the final MSW stream. The advantages of reusing plastics are: (i) Fossil Fuel consumption reduction as plastics consume 4-8% of global oil production (Perdan & Clift, 2004); (II) Energy and MSW reduction; (III) CO_2, NO_X, SO_2 emission reduction.

Sorting and separating PSW are the most crucial step in the recycling process (Kang & Schoenung, 2005), which must be held as early as possible so the recycler can obtain the best financial benefits of it. It is essential to identify the primary plastic in a given item fast and accurately and then sorting whether manual or automated must be done. In sorting plastic bottles, it is not always applicable to use automated methods as it came in various shapes and sizes, and also painting can impede the analysis. Density sorting methods are also used (popular in Asia) even when it is not so helpful as densities in most plastics are very close. A heavy medium sorting is often used in separating rigid PSW such as electronics wastes when a modifier or tetrabromoethan is added to water, but besides the high cost of these methods sometimes recovered plastics are contaminated through the process (Kang & Schoenung, 2005; Veit, Pereira, & Bernardes, 2002). Sometimes hydrocyclones which use centrifugal force is used to increase the density separation efficiency. However, this method is affected by many factors, such as material wettability, density variation, shape, size, and liberation from other materials. Also, a separated part of the material can float in a less density solution than clot material if air bubbles were attached to the surface if it was contaminated or poor wetted (APC, 1998).

Triboelectric separation is the most practical way to sort PSW. It is held by rubbing two resins against each other, so each material gains different charges to differentiate between them.

Result Technology AG (Switzerland) developed the speed accelerator technique which can be used to PSW sorting by using a high-speed accelerator to slice shredded waste then separate it by air filtration, screens, and electrostatics (Kang & Schoenung, 2005). Other techniques are used, such as X-ray fluorescent (XRF) spectroscopy and flame-retardants (FRs), which is used by MBA Polymers Inc to develop a pure resin separating technology (APC, 2003).

Removing paints from the PSW is one of the key challenges facing the recycler because recycled plastic properties can be changed as a result of the stress of the paint and coats (Kang & Schoenung, 2005). Many methods are used to in removing paints and coats of the PSW such as (i) Grinding which sometimes is associated with cryogenic method to obtain suitable liberation to avoid breaking down the plating material or be used by simply grind plastics to remove paints (Biddle & Dinger, 1999; Hopewell, Dvorak, & Kosior, 2009); (ii) Abrasion method for good size plastics; (iii) Solvent stripping by using a solvent to remove paint from plastics by dipping (Biddle & Dinger, 1999; Kang & Schoenung, 2005); (iv) The high-temperature aqueous-based which depends on hot water hydrolysis coatings, this methods is used with Olefin based plastics as it is not degradable in such circumstances. However, all the above methods are not fully satisfacting as they needed to be held under controlled conditions and also the resale value of the recycled plastics is degradated during the process.

2.2. Primary recycling of PSW

Primary recycle is to re-enter junk or single polymer plastics in a production line to obtain the same material product (Al-Salem & Lettieri, 2010; Sharratt, Lin, Garforth, & Dwyer, 1997)(Al-Salem, 2009a). Primary recycling is not as likable among recyclers as it needs semi-clean junk (Namias, 2013). Although the main source of PSW is households. It is still challenging to recycle household wastes as it requires the selective and segregated collection, and also collecting small quantities of PSW from various sources requires Kerbside systems, which makes the technology costly unsuitable for some countries (EEC, 2009).

2.2.1. Mechanical recycling

2.2.1.1. Overview

Restoring plastic products using mechanical ways to be reused in plastic products production is called mechanical recycling or secondary recycling (Mastellone, Perugini, Ponte, & Arena, 2002). This process is applicable only to single-polymer plastic as it became harder to apply when wastes are more complicated and contaminated. To obtain good end products sorting, cleaning, and preparation of PSW must be held. Degradation and heterogeneity are the most challenges face the recyclers as photo-oxidation and/or mechanical stresses occur due to chemical reactions on PSW. It is noted from the above reasons that financial and environmental practice can be held when it is assured that someone will buy the end product.

Mechanical recycling processes are the main source of many of our daily basis products, such as pipes, door profiles and bags. The main concern when considering a mechanically recycled item is the quality. The best PSW to be used in the mechanical recycling process are those generated from the plastic products synthesis, processing, and distribution because they separate clearly from different kinds of resin, they are available in large amounts, have low dirt and impurities.

2.2.1.2. Existing plants and technologies applied

Many steps are taken when mechanically recycle PSW, which recyclers try to reduce as it is a costly and energy-consuming process. This involves shredding, milling, or grinding to reduce the used plastic’s size to be a more convenient form (Zia et al., 2007). Usually used steps are (Aznar, Caballero, Sancho, & Francés, 2006):

- Grinding: large plastics are broken into small pieces.
- Impurity removal: impurities are removed in a cyclone.
- Floating: flakes are sorted according to density.
- Milling: usually, the first step of recycling when single-polymer plastics are ground together.
- Washing and drying: there are two washing stages a prewash stage at the beginning of the washing line and anther one afterword if additional treatment is required. The step uses water, but in some cases, chemical treatment is applied using surfactants and caustic soda (when remove glue of plastics).

- Agglutination: assembling the product to be sent to more steps or to be stored and sold.
- Extrusion: the plastic is emitted into filaments to form pellets that produce a single plastic polymer.
- Quenching: granulate the plastic using water to be sold.

Other different schemes are applied to other single polymer PSW like powdering and grinding foams (polyurethane, PU) using two-roll grinding, cooling mills, and sharp blades to be less than 0.2 mm in size. The 90% scrape took a 10% binder. Waste is ground and mixed with a binder and then is compressed. The product is then used as filler in polyester moulding compounds to increase the material toughness. Many products are produced from the flexible foams pieces recovery, such as athletic mats and carpet underlay.

Another scheme is re-bonding in which reused foam foils produced from the production of flexible foam sheets are blown from storage into a fixed drum with rotating knife cutters mixers where the adhesive mixture is sprayed into the foam flakes (Zia et al., 2007). This scheme assures obtaining a clean product with enhanced characterstices like hardness and density. It also provides flexibility and final product mechanical properties variability.

PVC is a good case of products produces by mechanical recycling. PVC composition and structure make it easy to be recycled mechanically to have excellent quality recycled material.

PET recycling is an excellent example of PSW utilizing. Two main schemes are used in recycling PET: methanolysis (chemical recycling) and mechanical recycling. The product formed are delivered to the textile and sheet-making plants, which use some techniques to melt the recycled material to produce sheets and textiles. These techniques are vacuum moulding, injection moulding, extrusion moulding, blow moulding, and inflated moulding.

2.2.2. Chemical recycling

2.2.2.1. Chemical recycling overview

Chemical (tertiary) recycle denotes the advanced processes that translate plastics into smaller molecules like gases or liquids, which are perfect to be used as raw materials for producing new plastics and petrochemicals (Mastellone et al., 2002). It is called chemical due to the change in the chemical structure of the polymer. Products generated are useful as fuel. The depolymerization processes technology is the reason behind its success as it results in an industrial scheme that is very sustainable, profitable, high product yield, and reduced waste. Chemical recycling encompasses advanced processes such as ovens, steam or catalytic cracking, viscosity breaking, liquid-gas hydrogenation, gasification, and pyrolysis, where PSW (polymer waste) is utilized as a reducing agent. Chemical recycling is receiving considerable attention as numerous fuel fractions from PSW is produced by this method.

Chemical recycling (mainly catalytic cracking, non-catalytic thermal cracking (thermolysis), and steam degradation) is paid more attention lately as a process of different fuel fractions production form PSW. Some polyamides (Nylon 66 and nylone 6 (PA6)) and polyethylene teraphthalate (PET) are because of their nature preferable for such treatment as they can be depolymerized efficiently. Polyethelene (PE) is selected as a preferred raw material for producing fuel technology.

Value-added outputs (artificial lubricants via PE thermal decaying) gain rising attention. Value-added recycling techniques development is very demanding because it increases the polymers recycling economic motivation (Horvat & Ng, 1999). Many chemical recycling techniques are used recently such as direct chemical treatment involves degradation by liquefaction, smelting with coke oven or blast furnace and gasification (Brems, Dewil, Baeyens, & Zhang, 2013; IEA Bioenergy, 2009; Kato, Nomura, & Uematsu, 2003; Yoji Ogaki, Koichi Tomioka, Atsushi Watanabe, Koji Arita, 2001). Degradation of condensation polymers such as nylon and PET to yield monomer units, i.e., monomer or raw material recycling, on the other hand, a mixture containing different components used as fuel is produced from vinyl polymers such as polyolefins (Yoshioka, Grause, Eger, Kaminsky, & Okuwaki, 2004). Many investigations on different degradation methods that obtain petrochemical are still held, and favorable conditions for gasification and pyrolysis are still under extensive researches (Aguado, Serrano, Miguel, Escola, & Rodríguez, 2007). The selective degradation of PSW is facilitated by catalytic cracking and reforming. Various reports have highlighted the utilization of solid catalysts like mesoporous materials, zeolites, ZSM-5, and silica-alumina. These catalysts effectively convert polyolefins into liquid fuel, yielding lighter fractions in comparison to thermal cracking.

The potentiality of treating contaminated and heterogeneous polymers with the limited need for pre-treatment is the primary advantage of chemical recycling. It is also a perfect solution if a 40% recycling scheme is targeted without dealing with very costly materials to separate and treat (Al-Salem, Lettieri, & Baeyens, 2009).

2.2.3. Thermolysis schemes and technologies

Thermolysis is PSW treatment with controlled temperature heat without catalysts. It can be divided into three subclasses: Pyrolysis, hydrogenation, and gasification.

2.2.3.1. Pyrolysis

Which results in obtaining energy and/or combustion gases and constituting molecules with a bonus of landfilling reduction (Mastral, Berrueco, & Ceamanos, 2007)? It is the process of advanced conversion technology where hydrocarbon content from a vast range of wastes is converted into clean, high calorific value gas, which is good enough to be used in electricity generation, boiler and engines without treatment. It also produces solid char that could be used onsite by burning or offsite through thermal processes. This process provides many advantages: (i) operational; by the reusing of char output as fuel or as a raw material for other petrochemical industries; besides, the flue gas produced does not need to clean up as it is clean before being used. (ii) environmentally; by reducing GHGs and CO_2 and providing an alternative solution to landfilling. (iii) financially; by producing easily marketed fuel with the high calorific value used to produce heat and electricity. Many disadvantages do exist for pyrolysis such as char handling (Ciliz, Ekinci, & Snape, 2004), final fuel treatment if a certain product is wanted, and the lack of knowledge about underlying reaction pathways that stopped the full distribution prediction.

Overview of pyrolysis plants

Separating pyrolysis from actual waste burnout is an engineering attempt to enhance the total waste incineration effectiveness (Malkow, 2004). Many technologies are used to obtain this such as : (i) PYROPLEQ®, AKZO process, ConTherm® technology, PKA pyrolysis technology, NRC process, The ProMelt process, BP polymer cracking process, NKT process and Noell pyrolysis process.

2.2.3.2. Gasification

Development and research in thermolysis technologies are encouraged because of MSW's high incineration cost and declining landfill space. Gasification produces combustion gases and fuels from waste (CPPIA, 2005). The main advantage of using air as a gasification agent is that replacing O_2 with air reduce cost, but the process's main disadvantage is inert N_2 presence in the air causes the calorific value of fuel produced is reduced. N_2 presence is reduced by introducing steam in a stoichiometric ratio. Gasification is not globally popular as it produced significant amounts of char that need more process to get rid of and also using costly pure oxygen. A complete gasification process should obtain completely combusted char, high calorific value gas, and easy separatable metal from ash and needs no additional installation to reduce air/water pollution. Some of the most Common gasification technologies are WGT gasification technology, Texaco gasification, SVZ process, and AKzo Nobel process.

2.2.3.3. final remarks on pyrolysis and gasification

Three different phases are produced from gasification and pyrolysis: a gas phase, a solid phase (Char, 2-25 wt%), and liquid phase (tars, 10-45 wt%) (Aznar et al., 2006; Zia et al., 2007). C_{20}-C_{50} products are first yield; then, in the gas phase, they cracked into lighter hydrocarbon like ethane and propene, which then formed aromatic compounds like benzene or toluene because of their instability in high temperatures. Hydrogen, coke, and methane may also be formed if residence time is long (Paradela, Pinto, Gulyurtlu, Cabrita, & Lapa, 1997; Westerhout, Kuipers, & Swaaij, 1998). Tar production is decreased, and char production is increased when a residence time of volatiles in the reactor is longer, and the temperature is higher (Cozzani, Nicolella, Rovatti, & Tognotti, 1997; Kumar & Singh, 2013). The controlling Chloride content in raw material and the threat to particle agglomeration causing fluidization are the main drawbacks of pyrolysis and gasification (Kaminsky, Schlesselmann, & Simon, 1995). To reduce tar content in produced gas temperature must be above 500 °C and gas residence time must be prolonged for pyrolysis and gasification of MSW, PSW, ASR and Biomass, coal and PSW mixtures (Ciliz et al., 2004; Miskolczi, Bartha, Deák, & Jóver, 2004; Pinto et al., 2002; Zolezzi, Nicolella, Ferrara, Iacobucci, & Rovatti, 2004). H_2, CO_2, CO, and CH_4, and lighter hydrocarbon is formed from cracking larger paraffines and olefins produced from plastic decomposition at 800 °C and above (Ponzio, Kalisz, & Blasiak, 2006).

Concluding from the above facts, more designed and engineered end product fashion could help further utilizing pyrolysis and gasification in industry.

2.2.3.4. Hydrogenation (hydrocracking):

Adding hydrogen chemically through an operation unit is hydrogenation (March, 1992). The Veba process is the leading hydrogenation PSW recycling technology applied. Coal is converted into gas oil and naphtha through liquefaction technology by Veba Oel AG®. The main products of the process are: off-gas, Hydrogenated solid residue, chlorine-free syncrude from the VCC section, and HCl.

2.2.3.5. Other chemical recycling schemes:

Degradative extrusion is one of many other chemical recycling technologies. IKV, Leuna, and Stahlwerkke Bremen are main degradative extrusion schemes used in PSW treatment where both chemical and mechanical energy is used to obtain high operating temperatures (Michaeli & Lackner, 1995). This process is the best engineering solution for small scale (10 kg/h). The benefits of degradative extrusion are (i) provides a breakdown of thermoplastics molecules; thus, polymers with low viscosity melts, (ii) combined chemical and mechanical recycle scheme improve the degradation process by providing gas, oxygen, steam, and catalysts if required (Michaeli & Lackner, 1995).

Another recycling PSW scheme is pure chemical routes such as hydrolysis, fractionation, hydroglycolysis, acid cleavage, aminolysis, and methanolysis. Hydrolysis is the first chemical recycling schemes that treat most PSW to produce both polyols (used effectively as fuels) and amine intermediates (used in producing virgin single-polymer plastics like PU) by breaking down PU, and other PSW uses heated, oxygen-free environment into gases, solids, and oils (Zia et al., 2007). Glycolysis is a standard chemical scheme used to treat PET and PU in which a polymer is reacted with diols at a temperature above 200 °C (Zia et al., 2007). Fractionation is another chemical treatment process. Treatment of PU containing material is an example of it (Zia et al., 2007).

2.2.3.6. Energy recovery

Producing energy in the form of heat, steam, and electricity by burning waste is energy recovery. A very high calorific value is produced when burning plastic materials as it is originated from crude oil. Plastic is a suitable energy source as its heating value is high besides; carbon dioxide and water production make it similar to fuels from petroleum (Brems et al., 2013; Morcos, 1989; Ryszard Wasilewski, 2013).

Reliability on landfilling is reduced as incineration of PSW reduces its volume by 90-99%. However, Emission of air pollutants such as CO_2, SO_X and NO_X, is the leading environmental concern associated with PSW co-incinerating. Smoke, VOCs, particulate-bound heavy metals, PCDFs are also generated from the process. Toxic substances (PAHs, nitro-PAHs, dioxine, etc.) were recognized in airborne particles from synthetic polymers combustion. To mitigate air emissions, several measures are implemented, including the introduction of ammonia into the combustion chamber, flue gas cooling, acid neutralization, and the incorporation of activated carbon and/or filtration for air emission capture and removal (Yassin, Lettieri, Simons, & Germana, 2005).

2.2.4. Two stage incineration and fluidised bed

In which bubbling fluidized beds (BFBs) is applied in the combustion of high plastic fraction MSW (ISOPA, 2001).

2.2.4.1. Rotary and cement kiln combustion

In a study conducted by Zevenhoven et al. in 2004, the behavior of nitrogen emissions from polymers and plastics in waste-derived fuel during rotary kiln combustion was investigated. The study revealed that the emissions of NO+NO2 were influenced by the nitrogen content of the fuel and the quantity of char generated from high-nitrogen fuel (Zevenhoven, 2004).

BSL is the primary technique used in incineration by rotary kilns. It can treat fluid, solid, and gaseous wastes into useful raw material and energy. Sometimes to reach the wanted high temperatures, liquid energy carriers or natural gas are added. This method can treat a mixture of high chlorinated wastes.

3. CONCLUSION

Recycling, treatment and recovery of PSW enriching the eco-image of waste management and decreasing single-life polymeric materials. The capability of combining recycle with the scrap re-extrusion process occurs in various scales with different thermoplastics by starting a loop of recycling in the processing line. Chemical treatment of PSW is the most sustainable choice as it recovers petrochemical raw material, provides a recycling route in the process and produces energy in the form of steam and heat. PSW has a recoverable energy that some time competes with other energy sources as it is oil derived. Reduce PSW volume and dependence on fossil fuels can be obtained when direct incineration is applied. This results in a good utility of natural resources and waste management schemes. However, the types, condition, suitability and intense energy consumption of the polymer based plastic are main issues relating to PSW. The properties of the by-products resulting from mechanical treatments should meet the marketable grade plastic properties regarding their type and monomer origin to be practically successful.

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