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REVIEW ARTICLE

A REVIEW ON CHALLENGES AND OPPORTUNITIES OF PLASTIC WASTE MANAGEMENT

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ABSTRACT

Solid waste management is one of the global challenges leading to environmental deterioration. Scientists are concerned about the recycling as well as reuse of Plastic waste. The major concern is to convert Plastic into energy by different methods. The present article reviews the challenges and future opportunities in waste management.

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INTRODUCTION

In 1862 Alexander Parkes invented the Plastics which are high molecular weight chains of carbon consisting of both synthetic as well as natural (Horodytska 2018). These synthetic polymers or semi-Synthetic organic materials are finding wide variety of applications in our day today life. In present times Global warming is serious environmental issue and it is directly linked with inappropriate disposal of Plastics disposal and its management is of major concerned (Bhadatata, Hoornweg 2015). Plastics are light weight, highly durable and is used in making furniture, household appliances, packing materials, corrosion-protected pipelines, bio-adsorbents (Pokhrel, 2019; Shrestha, 2019), containers, automobile and aircraft parts, 3D printing (Azeez, 2018), for medical applications (Phaiju, 2020), etc. There has been an increase in the production of Plastics, the global production shows increase by 250 million tons per year from 2009 to 2010 (Pandey *et al*., 2016), which further showed rise of around 320 million tons per annum in the year 2016 (Drzyzga & Prieto, 2018).European countries as well as China accounts for about 45 % of the global plastics production (i.e., 21.5 % and 23.5 %, respectively) in the year 2010(Nath, 2014). According to the CPCB (2018), India produces about 25940 tonnes of plastic garbage daily, and its improper management creates lots of environmental pollution. Only one-third of the total plastic wastes generated are suitable for recycling, based on their material composition (Chamas *et al*., 2020). Polypropylene (PP), polyethylene (PE), polystyrene(PS), poly vinyl chloride (PVC), etc. are some of the recyclable plastics (SWMRMC/UN-HABITAT, 2008). However, most of the plastic wastes are incinerated at dumping sites (Rigamonti *et al*., 2014).Large Plastic processing industries are directly supplying debris while commercial wastes are often produced from workshops, craftsmen shops, supermarkets, and wholesalers.

METHODOLOGY

As Plastic is being used is almost all the day to day activities and its utility is increasing day by day. There is no solo methodology which can be adopted for their reuse, and disposal (Dhokhikah & Trihadiningrum, 2012; Beyene, 2014). The perspective of its management depends entirely on the nature of plastics, and various countries have been executing different methods. In Austria, about 763, 500 tons of plastic wastes were handled in 1994, and about 75 % of the amounts were buried in controlled landfills.

During the end of 20th century, China started buying plastic wastes for recycling purposes (Goncalves,2018). Other countries like Canada, Germany, America and Bangladesh are working for sustainable plastic waste management using techniques like landfilling, biological degradation, composting, and chemical degradation (Shah, 2008). Nowadays, the use of different additives and hardeners with plastics decreases their biodegradability. Various countries have been practicing different approaches for solid plastic waste management, but none of these approaches are energy efficient and sustainable. It leads the undeveloped and developing countries manage their plastic wastes employing costly recycling or pyrolysis(catalytic and non-catalytic) processes. Nepal is following landfilling or dumping method (ICIMOD, 2018) to date and in the search of alternatives. It is an urgent need to collect plastics separately, unglued from other wastes such as glasses, metals (electrical stuffs/electronics), and compostable solids, as practiced in developed countries.

Landfilling: Not all the Plastic waste is fit for recycling process. Only around 5 to 25 % of Plastic waste is found to be fit for recycling process. Literature available suggest that large fraction of Plastic waste are put through landfill but this type of disposal of waste is unwanted because of high cost and this also leads to generation of large quantity of gases specially green house gases such as Hydrogen sulphide, Methane, CO. Also these plastics waste have very inferior degradability (Canopolietal., 2018). These dumped waste can catch unlimited fire and emit toxic radiations causing severe environmental pollution (Hidayah & Syafrudin, 2018). Landfills is not the solution to management of Plastic waste, however it provides space for waste residues and untreatable solid waste. However, it has been observed that these landfill site are not managed efficiently. The sites directly affect the human health specially the respiratory system and various skin diseases. As reported in ICIMOD, 2018 ,these landfill sites are not suitable for construction works for about 50years (ICIMOD, 2018).

Mechanical Recycling: Mechanical recycling is a process of re-processing plastic wastes employing comparatively high energy along with additives producing recycled product (Scaffaro 2019). This process involves following steps collection, sorting out, and reprocessing of waste into recycled products. Recycling of Plastic waste such as polyethylene terephthalate (PET) can be easily done as the recycling rate of PET is very higher in comparison to other plastics products. Recycled by this method (Hope well *et al*., 2009; Lu *et al*., 2012). Different spectroscopic and X-ray techniques are applied to sort out the plastic wastes (Ragaertetal., 2017).Various procedures of recycling are adopted based on the origin and composition of the waste materials. It makes method of recycling comparatively expensive (Ragaert *et al*., 2017). The crude shredder reduces the products to fist-sized particles, rotating drum washer, and fine shredder from washing reduces further in small-sized granules that are processed for further applications. The flow chart of the representative plant with the working principle of the mechanical recycling procedure is shown in Fig. 1. The float-sink separation, mechanical drier, and melt filter re-granulation work to separate PP and PE as float, and the other polymers such as PET, PS, and PVC as a sink in this method (Scaffaro *et al*., 2019; Ragaert *et al*., 2017).

Thermal recycling/ Pyrolysis: Thermal/ pyrolytic recycling is an alternative method for plastics waste management.

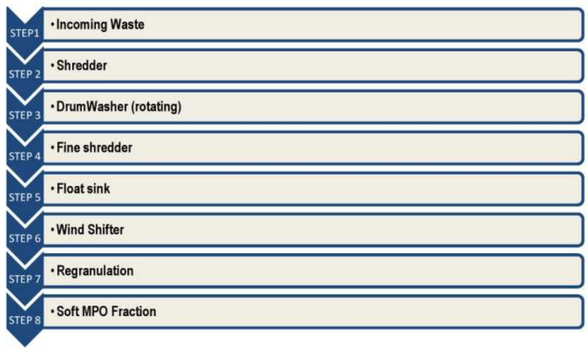

Fig 1. Mechanical Recycling Flow Chart

Although the chlorine content in PVC and other plastics is responsible for the formation of dioxins and furans during thermal recycling, the relationship between plastics fed into an incinerator and the generation of dioxins and furans is still unclear (Miskkolczi *et al*., 2004). The recycled PVC waste is used in plumbing pipes and fittings (Azeez,2018). The sheets of PVC waste after thermal recycling are also used in various fields such as blister packages, packaging, construction, human rehabilitation, electronics, food trays, house hold applications, automotive and aerospace components, etc. (Azeez, 2018). Thermal degradation of the polymeric materials which is also called thermal cracking or pyrolysis occurs in the absence or presence of oxygen temperature range maintained is 350 to 900º C. (Alla *et al*., 2014; Panda *et al*., 2010). Hydrocarbon oils consisting of paraffin, isoparaffins, olefins, naphthenes, and aromatic compounds are produced from the process, however, no condensable high calorific value gas during this process (Niziolek *et al*., 2017). It can also be carried out in presence of a catalyst (Al-Salem *et al*., 2017; Iwaya*et al*., 2002) with lower reaction temperatures (Gulab *et al*., 2010). Table 1 comparative data of thermal and catalytic pyrolysis of microcrystalline zeolites (Almeida &Marques, 2016).

Table 1. Comparative data of Thermal and Catalytic Pyrolysis

Production Yield (% wt)	Catalytic Pyrolysis	Thermal Pyrolysis
Solid Fraction	1.5	3.0
Liquid Fraction	35	84
Gas Fraction	63.5	13.0
C6-C12	99.92	56,55
C13-C23	0.09	37.78
>C23	0.0	5.66

Chemical Recycling: This method involves conversion of Polymers into their corresponding monomers , polymers are converted into their corresponding monomers (Achilias *et al*., 2007) which are utilized as a feed stock for a variety of down stream industrial processes and as transportation fuels. It involves three different processes such as Chemical cracking, depolymerisation and partial oxidation for recycling (Cunliffe*et al*., 2003). In the process of depolymerization, polymeric wastes are converted into sulfur-free liquid energy carriers by chemical recycling. These installations (80-85 %) allow the recovery of the energy contain in the plastic wastes. It is reported that 1 mg of depolymerised products of mixed plastics can carry around 4 to 6 calories of energy. Hence, this technique of conversion of plastics into alternative fuels is considered as a high-efficiency value and eco-friendly technology (Woloseiwicz- Glabetal., 2017; Sakata *et al*., 1999).

Polymers specially condensation such as polyamides, polyesters, nylons, polyethylene, terephthalate, etc. can be depolymerized via reversible synthesis reactions to initial di-acids and diols or diamines. The polymers are converted into their raw monomers via depolymerisation reactions such as alcoholysis, glycolysis, and hydrolysis, etc. (Kaminsky & Zorriqueta, 2007). Partial oxidation occurs in presence of oxygen or steam during which polymer wastes undergo combustion followed by the formation of light hydrocarbons, oxides of nitrogen, sulphur oxides, and dioxins. Similarly, other cracking processes such as hydro cracking, thermal cracking, and catalytic cracking are also reported (Beneroso *et al*., 2015). Typical feeds used in them include polyethylene, polyethylene terephthalate, polystyrene, polyvinyl chloride, and mixed polymers, polymer waste from municipal solid waste and other sources, polymers-coal co-mixture, refinery oils-coal (alone or co-processed) mixture, etc. (Dwivedi *et al*., 2019).

petro-based plastics such as polyethylene, polystyrene, polypropylene, etc. Hence, the research on bio-based polymeric materials with their end products as fertilizers have proliferated in recent years (Ciriminna & Pagliaro, 2020, Fesseha &Abebe, 2019). The microorganisms such as *Comamona sacidovorans, Fusarium solani, Phanerochaete chrysosporium* contribute to degradation of plastics in presence of enzymes such as lipases, cutinase, and manganese peroxide (Table 2). Plastics undergo biodegradation producing biofilms, oligomers, monomers, and substrates. Polypropylene can also be degraded by its exposure to UV radiation from sunlight and it can also be oxidized at high temperatures. Different characterization techniques such as differential scanning calorimetry (DSC), Fourier transform infrared spectroscopy (FTIR),nuclear magnetic resonance spectroscopy (NMR), X-Ray diffraction (XRD), contact angle measurements, X-ray photoelectron spectroscopy (XPS),water uptake experiment, etc., are applied to assess the biological

Table 2. Biological degradation of Plastics

Substrate (Plastic)	**Microorganism**	**Enzyme utilized**	**Simple form**	**References**
Polyurethane	*Comamonasacidovorans*	Lipases	-	(Howard,2011)
Polyethylene	*Penicillium oxalicum* & *Penicillium chrysogenum*	-	Biofilm	(Ojha*etal.,* 2017)
Polystyrene	*Rhodococcusruber*	-	Biofilm	(Mor&Sivan, 2008)
Nylon	*Phanerochaetechrysosporium*	Manganese peroxidase	Oligomers	(Iiyoshi *etal.,* 1998)
Polyvinylchloride	*Pseudomonasfluorescens* B-22	-	Substrate	(Danko *etal.,* 2004)
Polypropylene	*Bacillus cereus* & *Sporosarcinaglobispora*	-	-	(Helen*etal.,* 2017)
Polycaprolactone	*Fusariumsolani*	Cutinase	-	(Murphy*et al.,* 1996)

Biological Recycling: Biological recycling is the methodology in which microorganisms (bacteria, actinomycetes, and fungi) degrade the plastics, and waste polymeric materials producing CO_2, H_2O, and microbial biomass, as the final products of the reaction (Kujawa *et al*., 2007, Cerqueira *et al*., 2016). Different types of micro organisms and their different pathways (such as aerobic and anaerobic) related with polymer degradation are often determined by the environmental factors (Fesseha & Abebe, 2019; Singh & Rawat,2019). The microorganisms such as Gram-positive and Gram-negative bacteria as well as a few species of fungal origin like Aspergillus are particularly involved. Species of microbes like Streptococcus, Staphylococcus, Micrococcus (Gram-positive), Moraxella and Pseudomonas (Gram-negative), and species of fungi (Aspergillus glaucus and Aspergillus niger) are associated with biodegradation of plastics. Besides Pseudomonas fluorescens B-22, Phanerochaete chrysosporium, Rhodococcusruber, Penicilliumoxalicum Bacilluscereus, etc., are involved in breaking down the plastics/polymers such as polyvinylchloride, nylon, polystyrene, polyethylene, and polypropylene respectively (Mor & Sivan, 2008; Ojha. ,2017; Helen, 2017).

In Biological Recycling, Biodegradation and composting regularly used as synonymous terms but they are not same, and their exact mechanism of biological recycling is still unknown and yet to be developed. There are many possible predicted mechanisms of bio-recycling, a simple one is shown in Fig. 2 (Fesseha & Abebe, 2019).During biological recycling of polymeric solid waste products, the formation of methane, Carbon dioxide, water, and metabolic products such as sugars, etc., are commonly formed which are useful for plant growth. The composted final products of waste plastics are used as fertilizers. Bio-based plastics such as PLA, PHB, polyesters, etc., are hydrolyzed and degraded more easily in comparison to

degradation of plastics (Abdelaal, 2014). Natural fibers-filled polymer composites have low mechanical and optical properties; however, they are more brittle in comparison to petro-based polymers/plastics (Bhandari *et al*., 2019). In present times, researchers and scientists are preparing polymeric materials using naturally available and degradable materials to replace petro-based plastics to bio-based. The polymer films such as cellulose, polylactic acid, polycaprolactone, etc., degrade faster in the soil compared to polyethylene, polyvinyl chloride, polystyrene (Bhandari *et al*., 2021a, 2021b).

Plastic waste management during COVID-19 pandemic: During Covid-19 the maximum use of masks, gloves, and personal protective equipment (PPE kits) by health workers, patients, and common man was observed (Prata, 2020; Rothan & Byra Reddy,2020). These materials require proper management and disposal from an environmental point of view (Prata *et al*., 2020; Fan *et al*., 2021).

Synthesis of carbon dots(C-dots): Carbon dots finds application in photo-catalysis specially for the decomposition of environmental pollutants, sensors and solar cells, bio-imaging, etc. (Aji *et al*., 2018). Recent studies showed that plastic wastes are also used for the preparation of C-dots. The rearrangement occurs in the Carbon chains of plastics (both bio and petro-based) during polymerization and carbonization processes leading to the formation of C-dots (Kumaletal., 2018, Lauria & Lizundia, 2020; Hu *et al*., 2021). C-dots are tiny particle size (<10nm) and possess fluorescence. PLA, Polyethylene (PE), PEG, polystyrene (PS), polypropylene (PP), poly vinyl chloride (PVC), poly vinyl alcohol(PVA), polyacrylic acid(PAA), and some of the polymeric species are used as raw materials for the preparation of C-dots(Hu*et al*., 2021). Similarly, Aji *et al*. (2018) synthesized C-dots nanoparticles using waste plastic bags of polypropylene(PP) at different temperature such as 200°C, 250°C, and 300°C. During the process of synthesis of C-dots from solid wastes, biological by-products are formed. Hence, this process of synthesis of C-dots from polymers is also an environment-friendly method for plastics waste management (Lauria & Lizundia, 2020).

Economic and Environmental feasibility of plastic waste management: The economy and technology play a requisite role in plastic recycling and waste management (Renzini *et al*., 2009; Aho etal., 2007). Plastic recycling is further divided into material recycling and energy recovery (Pendern & Yang,2019) . Mechanical recycling is the most preferred mode of recycling. Nowadays, scientists have developed many methodology of moderation of plastic wastes for their multiple-use as well as proper management.
There is emergence of alternative utility materials such as plastic bricks, road construction materials, etc., from the waste materials (Sasidharan *et al*., 2019). The evolution of such techniques helps to minimize the mass of plastic wastes releasing into the earth's crust as well as decreases the cost of useful materials production (Brasileiro *et al*., 2019; Horvath *et al*., 2018; Siddique *et al*., 2008). Many countries like Netherlands, South Africa, India, Ghana, Ethiopia etc have administered the strategy of using plastic wastes for construction of roads (Sasidharan *et al*., 2019). The waste plastics have been utilised in bituminous road construction, and when added in small amount (approx 5-10wt.%) helps in notable improvement in various mechanical properties such as of strength, stability, fatigue life, and other desirable properties, longevity, and pavement (Sasidharan *et al*., 2019). Even Nepal has also developed some methods (plastic fuel production, plastic tar for road construction) to use plastic waste and contribute to the control of environmental pollution (The Himalayan Times, 2018). It is almost impossible to completely curb plastic production immediately due to which sustainable plastic management is an urgent task.

An Alternate Solution: Degradable or compostable plastics and their composite materials: Bio-plastics, Degradable Plastics, Natural polymers fibers, biomaterials, green materials etc., are the possible alternatives to address all of the above-mentioned challenges. However, the properties of these polymers and materials cannot be perfectly suitable for applications. Therefore, the evolution of implementation-based eco-friendly novel materials (such as composites, blends, etc.) based on these benign polymers can be a solution. An immediate action to collect the plastics waste scientifically and manage with best alternatives besides landfilling is needed. In India, Plastic waste is used in the construction of thousands of kilometers of road in recent years. Furthermore, PGA, PLA, Natural fibers, starch, cellulose, etc., are presently used as natural polymers (Adhikari *et al*., 2012a, 2012b; Bhandari, 2017; Bhandari *et al*., 2018; Wittel *et al*., 2003). Similarly, poly butylenes adipate terephthalate (PBAT), poly hydroxyl alkanoates (PHA), poly (alkylene dicarboxylate), etc., are degradable polymers, i.e. both on the soil surface and under burial. They undergo both enzymatic degradation and chemical hydrolysis (degradation) (Weietal., 2018). UV radiations as well as microorganism are used for degradation of Biopolymers and Bioplastics. Thus, from the economic and ecological/environmental point of view, plastic reuse, recycling, and their substitution by natural and degradable polymeric materials is another way to bring down non-degradable petroleum-based commodity plastics.

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