Journal of Basic and Applied Engineering Research
p-ISSN: 2350-0077; e-ISSN: 2350-0255; Volume 3, Issue 4; April-June, 2016, pp. 371-376

http://www.krishisanskriti.org/Publication.html

Conversion of Mixed Waste Plastics into Liquid Fuel–An Alternative Approach for Solid Waste Minimization

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Abstract—*Solid waste management is one of the most essential functions in a country to achieve a sustainable development. In India, it has been one of the least prioritized functions during the last decades. The most common ways to treat waste in India today are open dumping and uncontrolled burning. These methods are causing severe environmental pollution and health problems. India is one of the world's largest emitter of methane gas from waste disposal. Since methane is a strong greenhouse gas, even small emissions have large impact on the climate. Improper treatment of waste will also affect peoples' health, first of all by the spreading of toxic compounds from uncontrolled burning and secondly by leakage of sewage from the dumping grounds into the groundwater. Plastics in municipal solid waste streams make up only 7–9% of the weight of the total waste stream, by volume they may represent 20–30%. Plastic waste has attracted widespread attention in India, particularly in the last five years, due to the widespread littering of plastics on the landscape of India. Conversion of waste plastics in an inert atmosphere has been regarded as a productive method for solid waste minimization, because this process can convert waste plastics into liquid hydrocarbons by pyrolysis that can be used either as fuel or as a source of chemicals. The present paper reports the production and consumption of waste plastics, different methods of solid waste management with special reference to thermochemical degradation of mixed waste plastics to liquid fuel.*

1. INTRODUCTION

Solid waste management is a challenge for the cities' authorities in developing countries mainly due to the increasing generation of waste, the burden posed on the municipal budget as a result of the high costs associated to its management, the lack of understanding over a diversity of factors that affect the different stages of waste management and linkages necessary to enable the entire handling system functioning. Rapid industrialization and population explosion in India has led to the migration of people from villages to cities, which generate thousands of tons of solid wastes (SW) or precisely Municipal Solid waste (MSW) daily. The MSW amount is expected to increase significantly in the near future as the country strives to attain an industrialized nation status by the year 2020. Poor collection and inadequate transportation are responsible for the accumulation of MSW at every nook and corner. The management of MSW is going through a critical phase, due to the unavailability of suitable facilities to treat and dispose of the larger amount of MSW generated daily in metropolitan cities. Unscientific disposal causes an adverse impact on all components of the environment and human health. Improper management of municipal solid waste (MSW) causes hazards to inhabitants. Various studies reveal that about 90% of MSW is disposed of unscientifically in open dumps and landfills, creating problems to public health and the environment.

Management of solid waste reduces or eliminates adverse impacts on the environment and human health and supports economic development and improved quality of life. A number of processes are involved in effectively managing waste for a municipality. These include monitoring, collection, transport, processing, recycling and disposal. Waste management has become one of the most significant problems of our time so as to preserve the lifestyle, while also protecting the environment and public health despite large generation of waste.

The sources of solid waste include residential, commercial, institutional, and industrial activities. Certain types of wastes that cause immediate danger to exposed individuals or environments are classified as hazardous; these are discussed in the article hazardous-waste management. All non-hazardous solid waste from a community that requires collection and transport to a processing or disposal site is called refuse or municipal solid waste (MSW). Refuse includes garbage and rubbish. Garbage is mostly decomposable food waste; rubbish is mostly dry material such as glass, paper, cloth, or wood. Garbage is highly putrescible or decomposable, whereas rubbish is not. Trash is rubbish that includes bulky items such as old refrigerators, couches, or large tree stumps. Trash requires special collection and handling. Construction and demolition (C&D) waste (or debris) is a significant component of total solid waste quantities (about 20 percent in the United States), although it is not considered to be part of the MSW stream. However, because C&D waste is inert and non-hazardous, it is usually disposed of in municipal sanitary landfills. Another type of solid waste, perhaps the fastest-growing component in many developed countries, is electronic waste, or e-waste, which includes discarded computer equipment, televisions, telephones, and a variety of other electronic devices.

1.1. Functional elements of solid waste management

Functional element	Functional element
Waste generation	Waste generation encompasses those activities in which materials are identified as no longer being of value and are either thrown away or gathered together for disposal. What is important in waste generation is to note that there is an identification step and that this step varies with each individual. Waste generation is, at present, an activity that is not very controllable.
Waste handling and separation, storage, and processing at the source	Waste handling and separation involve the activities associated with managing wastes until they are placed in storage containers for collection. Handling also encompasses the movement of loaded containers to the point of collection. Separation of waste components is an important step in the handling and storage of solid waste at the source. On-site storage is of primary importance because of public health concerns and aesthetic considerations
Collection	Collection includes both the gathering of solid wastes and recyclable materials and the transport of these materials, after collection, to the location where the collection vehicle is emptied, such as a materials-processing facility, a transfer station, or a landfill.
Transfer and transport	The functional element of transfer and transport involves two steps: (1) the transfer of wastes from the smaller collection vehicle to the larger transport equipment, and (2) the subsequent transport of the wastes, usually over long distances, to a processing or disposal site. The transfer usually takes place at a transfer station. Although motor vehicle transport is most common, rail cars and barges are also used to transport wastes.
Separation, processing, and transformation of solid waste	The means and facilities that are now used for the recovery of waste materials that have been separated at the source include curb side collection and drop off and buyback centres. The separation and processing of wastes that have been separated at the source and the separation of commingled wastes usually occurs at materials recovery facilities, transfer stations, combustion facilities, and disposal sites. Transformation processes are used to reduce the volume and weight of waste requiring disposal and to recover conversion products and energy. The organic fraction of MSW can be transformed by a variety of chemical and biological processes. The most commonly used chemical transformation process is combustion, used in conjunction with the recovery of energy. The most commonly used biological transformation process is aerobic composting.
Disposal	Today, disposal by landfilling or land spreading is the ultimate fate of all solid wastes, whether they are residential wastes collected and transported directly to a landfill site, residual materials from MRFs, residue from the combustion of solid waste, compost, or other substances from various solid waste processing facilities. A modern sanitary landfill is not a dump. It is a method of disposing of solid wastes on land or within the earth's mantle without creating public health hazards or nuisances

In 2006 e-waste made up 5 percent of the total solid waste stream, and the United Nations Environment Program estimated that developed countries would triple their output of e-waste by 2010. Concern over this type of waste is escalating. Lead, mercury, and cadmium are among the materials of concern in electronic devices, and governmental policies may be required to regulate their recycling and disposal.

2. TREATMENT OF SOLID WASTE

Treatment of solid waste can be classified as follows:

2.1. Thermal treatment

This refers to processes that involve the use of heat to treat waste. Listed below are descriptions of some commonly utilized thermal treatment processes.

2.1.1. Incineration

Incineration is the most common thermal treatment process. This is the combustion of waste in the presence of oxygen. After incineration, the wastes are converted to carbon dioxide, water vapor and ash. This method may be used as a means of recovering energy to be used in heating or the supply of electricity. In addition to supplying energy incineration technologies have the advantage of reducing the volume of the waste, rendering it harmless, reducing transportation costs and reducing the production of the greenhouse gas methane

2.1.2. Pyrolysis and gasification

Pyrolysis and gasification are similar processes they both decompose organic waste by exposing it to high temperatures and low amounts of oxygen. Gasification uses a low oxygen environment while pyrolysis allows no oxygen. These techniques use heat and an oxygen starved environment to convert biomass into other forms. A mixture of combustible and non-combustible gases as well as pyroligenous liquid is produced by these processes. All of these products have a high heat value and can be utilized. Gasification is advantageous since it allows for the incineration of waste with energy recovery and without the air pollution that is characteristic of other incineration methods.

2.1.3. Open burning

Open burning is the burning of unwanted materials in a manner that causes smoke and other emissions to be released directly into the air without passing through a chimney or stack. This includes the burning of outdoor piles, burning in a burn barrel and the use of incinerators which have no pollution control devices and as such release the gaseous by products directly into the atmosphere (Department of environmental quality 2006). Open- burning has been practiced by a number of urban centres because it reduces the volume of refuse received at the dump and therefore extends the life of their dumpsite. Garbage may be burnt because of the ease and convenience of the method or because of the cheapness of the method. In countries where house holders are required to pay for garbage disposal, burning of waste in the backyard allows the householder to avoid paying the costs associated with collecting, hauling and dumping the waste.

Open burning has many negative effects on both human health and the environment. This uncontrolled burning of garbage releases many pollutants into the atmosphere. These include dioxins, particulate matter, polycyclic aromatic compounds, volatile organic compounds, carbon monoxide, hexa chloro benzene and ash. All of these chemicals pose serious risks to human health. The Dioxins are capable of producing a multitude of health problems, they can have adverse effects on reproduction, development, disrupt the hormonal systems or even cause cancer. The polycyclic aromatic compounds and the hexachlorobenzene are considered to be carcinogenic. The particulate matter can be harmful to persons with respiratory problems such as asthma or bronchitis and carbon monoxide can cause neurological symptoms.

The harmful effects of open burning are also felt by the environment. This process releases acidic gases such as the halo-hydrides; it also may release the oxides of nitrogen and carbon. Nitrogen oxides contribute to acid rain, ozone depletion, smog and global warming. In addition to being a greenhouse gas carbon monoxide reacts with sunlight to produce ozone which can be harmful. The particulate matter creates smoke and haze which contribute to air pollution.

2.1.4. Dumps and Landfills

2.1.4.1. Sanitary landfills

Sanitary Landfills are designed to greatly reduce or eliminate the risks that waste disposal may pose to the public health and environmental quality. They are usually placed in areas where land features act as natural buffers between the landfill and the environment. For example the area may be comprised of clay soil which is fairly impermeable due to its tightly packed particles, or the area may be characterized by a low water table and an absence of surface water bodies thus preventing the threat of water contamination.

In addition to the strategic placement of the landfill other protective measures are incorporated into its design. The bottom and sides of landfills are lined with layers of clay or plastic to keep the liquid waste, known as leachate, from escaping into the soil. The leachate is collected and pumped to the surface for treatment. Boreholes or monitoring wells are dug in the vicinity of the landfill to monitor groundwater quality.

A landfill is divided into a series of individual cells and only a few cells of the site are filled with trash at any one time. This minimizes exposure to wind and rain. The daily waste is spread and compacted to reduce the volume, a cover is then applied to reduce odors and keep out pests. When the landfill has reached its capacity it is capped with an impermeable seal which is typically composed of clay soil.

Some sanitary landfills are used to recover energy. The natural anaerobic decomposition of the waste in the landfill produces landfill gases which include Carbon Dioxide, methane and traces of other gases. Methane can be used as an energy source to produce heat or electricity. Thus some landfills are fitted with landfill gas collection (LFG) systems to capitalize on the methane being produced. The process of generating gas is very slow, for the energy recovery system to be successful there needs to be large volumes of wastes.

These landfills present the least environmental and health risk and the records kept can be a good source of information for future use in waste management, however, the cost of establishing these sanitary landfills are high when compared to the other land disposal methods.

Controlled dumps are disposal sites which comply with most of the requirements for a sanitary landfill but usually have one deficiency. They may have a planned capacity but no cell planning, there may be partial leachate management, partial or no gas management, regular cover, compaction in some cases, basic record keeping and they are fenced or enclosed. These dumps have a reduced risk of environmental contamination, the initial costs are low and the operational costs are moderate. While there is controlled access and use, they are still accessible by scavengers and so there is some recovery of materials through this practice.

2.1.4.2. Bioreactor landfills

Recent technological advances have led to the introduction of the Bioreactor Landfill. The Bioreactor landfills use enhanced microbiological processes to accelerate the decomposition of waste. The main controlling factor is the constant addition of liquid to maintain optimum moisture for microbial digestion. This liquid is usually added by re-circulating the landfill leachate. In cases where leachate in not enough, water or other liquid waste such as sewage sludge can be used. The landfill may use either anaerobic or aerobic microbial digestion or it may be designed to combine the two. These enhanced microbial processes have the advantage of rapidly reducing the volume of the waste creating more space for additional waste, they also maximize the production and capture of methane for energy recovery systems and they reduce the costs associated with leachate management. For Bioreactor landfills to be successful the waste should be comprised predominantly of organic matter and should be produced in large volumes.

3. PLASTICS WASTE MANAGEMENT

In recent years the consumption of plastics has increased drastically; as a consequence the responsible disposal of plastic wastes has created serious social and environmental arguments [1]. Significant aspect of plastics material growth globally has been the innovation of newer application areas for plastics such as increasing plastics applications in automotive field, rail, transport, defence & aerospace, medical and healthcare, electrical & electronics, telecommunication, building & infrastructure, furniture, etc [2].

Plastic waste is one of the major components of solid waste and its presence in the waste stream poses a serious problem due to their non-biodegradability and high visibility in the waste stream. Plastic in municipal solid waste streams make up only 7- 9% of the weight of the total waste stream, by volume they may represent 20-30%. Of the organic waste stream, that is, after removal of glass, metals, etc., plastics are about 9-12% by weight.

Table 3.1: Plastics consumption in some selected Continents of the World.

Rank	Continent	2013
1	Asia	34%
2	North America	30%
3	Western Europe	27%

Plastics production has increased by an average of almost 10% every year on a global basis. Worldwide Plastics Industry witnessed a steady growth in the last few decades, 7 million tons in the world in 1960 to 196 million tons in 2005 and to continue reaching over 365 million tons in 2015, 540 million tons in 2020, using a more conservative annual rate of 6.5 % [3]. Asia has been world’s largest plastics consumer for several years, accounting for about 34% of the global consumption excluding Japan, which has share of about 6.8%. Next to Asia is North America with 30% share, then Western Europe with 27% share in the global market [2].

Table 3.2: Consumption and growth rate of per capita consumption of plastics in some selected countries.

Rank	Country	2013 (MMT)	2013 (Growth Rate)
1	USA	41.8	4.2%
2	China	35.3	9.1%
3	India	18.5	16%

The current growth rate in Indian polymer consumption (16% p.a.) is clearly higher than that in China (10% p.a.) [4]. The per capita consumption of plastic in the country stood at 8 kg in 2010 and is expected to go up to 13 kg by the end of 2013 [5]. A logistic function of the form expressed has been used to estimate the per capita consumption figures for India in the coming years: :

$$Y_t = Y_{max}/(1+e^{a-bt})$$

Where: Yt is consumption level at time t;

Ymax is saturation point for consumption for the time series considered; a and b are parameters, determined econometrically [6]. Polyolefins account for the major share of 60% in the total plastics consumption in India. Packaging is the major plastics consuming sector, with 42% of the total consumption, followed by consumer products and the construction industry [4].

3.1. Technological, economic and ecological options for management of waste polymers

Recycling of plastics should be carried in such a manner to minimize the pollution level during the process and as a result to enhance the efficiency of the process and conserve the energy. Plastics recycling technologies have been historically divided into four general types - primary, secondary, tertiary and quaternary.

Primary recycling involves processing of a waste/scrap into a product with characteristics similar to those of original product.

Secondary recycling involves processing of waste/scrap plastics into materials that have characteristics different from those of original plastics product.

Tertiary recycling involves the production of basic chemicals and fuels from plastics waste/scrap as part of the municipal waste stream or as a segregated waste.

Quaternary recycling retrieves the energy content of waste/scrap plastics by burning/incineration.

Waste Plastics are mostly land filled or incinerated; however, these methods are facing great social resistance because of environmental problems such as air pollution and soil contamination, as well as economical resistance due to the increase of space and disposal costs. In a long term neither the land filling nor the incineration solve the problem of wastes, because the suitable and safe depots are expensive, and the incineration stimulates the growing emission of harmful and greenhouse gases e.g. NOx, SOx, COx etc. Plastic is derived from petrochemical resources. In fact these plastics are essentially solidified oil. They therefore have inherently high calorific value [1].

With a view to the environment protection and reduction of non-regeneration resource, recycling technology for converting to oil from plastic waste has drawn much attention in the world. Plastics pyrolysis, on the other hand, may provide an alternative means for disposal of plastic wastes with recovery of valuable liquid hydrocarbons. In pyrolysis or thermal cracking, the polymeric materials are heated to high temperatures, so their macromolecular structures are broken down into smaller molecules and a wide spectrum of hydrocarbons are formed. These pyrolytic products can be divided into a gas fraction, a liquid fraction consisting of paraffins, olefins, naphthenes and aromatics (PONA), and solid residues.

Recycling and re-refining are the applicable processes for upgrading of petroleum based plastic wastes (PBPWs) by converting them into reusable products such as gasoline and heavy oil. PBPW is a source of useful energy (fuels) and/or chemicals and has many advantages from an ecological point of view. Possible acceptable processes are cracking or pyrolysis. The cracking process yields a highly unstable low-grade fuel oil which can be acid-corrosive, tarry, and discolored along with a characteristically foul odour.

The pyrolysis process consists of the thermal degradation of the wastes in the absence of oxygen/air. Plastics pyrolysis may provide for disposal of plastic wastes with recovery of valuable gasoline-range hydrocarbons. In pyrolysis, the polymeric materials are heated to high temperatures, so their macromolecular structures are broken down into smaller molecules and a wide range of hydrocarbons are formed. These pyrolytic products can be divided into a gas fraction, a liquid fraction consisting of paraffins, olefins, naphthenes and aromatics, and solid residues. Pyrolysis appears to be a technique which is able to convert PBPWs into gasoline-range hydrocarbons.

3.2. Thermal pyrolysis of mixed waste plastics

Thermal cracking or pyrolysis, involves the degradation of the polymeric materials by heating in the absence of oxygen. The process is usually conducted at temperatures between 500-800 ºC and results in the formation of a carbonized char and a volatile fraction that may be separated into condensable hydrocarbon oil and a non-condensable high calorific value gas. The proportion of each fraction and their precise composition depends primarily on the nature of the plastic waste but also on process conditions.

A. Demirbas et al. have done on non catalytic cracking of waste plastics of polystyrene (PS), Polyethylene (PE) and polypropylene (PP) in a stainless steel tube reactor. Under pyrolysis conditions, plastic wastes can be decomposed into three fractions: gas, liquid and solid residue. The degradation finished between 720 and 760K for the PS, PE and PP waste plastics. The liquid products from plastic wastes could be considered as a mixture of heavy naphtha (C7–C10), gasoline (C8–C10) and light gas oil (C10–C20) fractions. The gaseous products typically contain C1–C4 paraffinic hydrocarbons with some olefins. As such, most of the liquid products formed would be ideally suited to further processing in a petrochemical refinery, with the gases used directly as fuels [6].

N. Miskolczi et al. studied the degradation of different mixtures of the most frequently occurring waste polymers (polyethylene, polypropylene, polystyrene, polyamide, ethylene-propylene copolymer and polyurethane rubber) was investigated in a horizontal tube reactor. The cracking equipment consisted of three main parts: an extruder, a reactor and a separator. The degradation behavior of polymer mixtures was investigated at three different temperatures (500, 525, 550 oC) and residence times (0.6, 0.9, 1.2 h). They concluded that the yields of volatile products increased both with temperature and residence time. The yields of liquids of 10-25% separated from the gases leaving the reactor could be increased further by 10-15% by distilling the residue [7].

L. Sorum et al. The large variety in municipal solid waste (MSW) composition and differences in thermal degradation behaviour of MSW components studied for modelling, design and operation of thermal conversion system. The pyrolysis of 11 different components including plastics has been investigated in an inert atmosphere at 10 oC/min heating rate. PS, PP, LDPE, HDPE were all modelled as single order reactions describing the degradation of hydrocarbon polymers. The degradation of PVC was modelled with three parallel reactions [8].

3.3. Catalytic pyrolysis of mixed waste plastics

A suitable catalyst is used to carry out the pyrolysis reaction. The presence of catalyst lowers the reaction temperature and time. Catalytic pyrolysis yields a much narrower product distribution of carbon atom number with a peak at lighter hydrocarbons and occurs at considerably lower temperatures as compared to thermal pyrolysis. From an economic perspective, reducing the cost even further will make this process an even more attractive option. This option can be optimized by reuse of catalysts and the use of effective catalysts in lesser quantities.

K. H. Lee has been investigated the upgradation of pyrolytic oil produced from Municipal plastics waste (MPW) using FCC catalyst as a pyrolysis catalyst. The degradation process using FCC as a catalyst showed the improvement of liquid and gas yields and also high fraction of heavy hydrocarbons in oil product due to more cracking residue [9].

M. Syamsiro et al. has been carried out the sequential pyrolysis and catalytic reforming of Indonesian municipal plastic wastes over Y-zeolite and natural zeolite catalysts. The results show that the feedstock types strongly affect the product yields and the quality of liquid and solid products. HDPE waste produced the highest liquid fraction. Pyrolysis with natural zeolite catalyst produced higher liquid product compared with Y-zeolite catalyst [10].

4. CONCLUSION

The informal policy of encouraging the public to separate solid waste and market it directly to the informal network appears to be a better option. The involvement of people and private sector through NGOs could improve the efficiency of solid waste management. Public awareness should be created among masses to inculcate the health hazards of the wastes.

Consumption of plastics is increasing day by day due to its wide field applications and therefore results in increase in plastics waste. However, the huge amount of plastic wastes produced may be treated with suitably designed method to produce fossil fuel substitutes. The method should be superior in all respects (ecological and economical). So, a suitable process which can convert waste plastic to hydrocarbon fuel if designed and implemented then that would be a cheaper partial substitute of the petroleum without emitting any pollutants. It would also take care of hazardous plastic waste and reduce the import of crude oil. The thermal and catalytic pyrolysis of waste plastics to fuel seem to be prominent methods for the minimization of plastic waste which are being adopted in different countries recently due to its efficiency over other process in all respects. Conversion of waste plastics into liquid fuels by pyrolysis can also be a vital technique for the solid waste management.

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