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An overview for exploring the possible routes of recycling Industrial Plastic Waste (IPW)

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***Abstract*- Industrial plastic wastes arising from the large plastics manufacturing, processing and packaging industries have relatively good physical characteristics i.e. they are sufficiently clean and free of contamination and are available in fairly large quantities. The most of this waste fraction is composed of PP/PE bags and drums etc., which can be mechanically recycled and can be processed by thermal decomposition**

This research consists of various recycling and recovery methods for industrial plastic waste and treatment methods for IPW. Thermochemical conversion and its kinetic study is main concern of this research.

Index Terms- Industrial waste-plastic; Thermochemical conversion; Degradation model; Activation energy, pyrolysis.

1. INTRODUCTION

1.1 Recycling and recovery routes of Industrial waste plastic:

Primary recycling, better known as re-extrusion, is the re-introduction of scrap, industrial or single-polymer plastic edges and parts to the extrusion cycle in order to produce products of the similar material. This process utilizes scrap plastics that have similar features to the original products (Al-Salem, 2009a). Primary recycling is only feasible with semi-clean scrap, therefore making it an unpopular choice with recyclers.

A valid example of primary recycling is the injection molding of out of specification LDPE crates (Barlow, 2008). Crates that do not meet the specifications are palletized and reintroduced into the recycling loop or the final stages of the manufacturing. Currently, most of the PSW being recycled is of process scrap from industry recycled via primary recycling techniques. In the India, process scrap represents 250,000 tons of the plastic waste and approximately 95% of it is primary recycled. Primary recycling can also involve the re-extrusion of post-consumer plastics. Generally, households are the main source of such waste stream. However, recycling household waste represents a number of challenges, namely the need of selective and segregated collection. Curbside systems are required to collect relatively small quantities of mixed IPW from a large number of sources.

1.1.1 Mechanical recycling:

Mechanical recycling, also known as secondary recycling, is the process of recovering plastic solid waste (IPW) for the re-use in manufacturing plastic products via mechanical means. It was promoted and commercialized all over the world back in the 1970s. Mechanical recycling of IPW can only be performed on single-polymer plastic, e.g. PE, PP, PS, etc. The more complex and contaminated the waste, the more difficult it is to recycle it mechanically. Separation, washing and preparation of IPW are all essential to produce high quality, clear, clean and homogenous end-products. One of the main issues that face mechanical recyclers is the degradation and heterogeneity of IPW. Since chemical reactions that constitute polymer formation (i.e. polymer addition, polymerization and polycondensation) are all reversible in theory, energy or heat supply can cause photo-oxidation and/or mechanical stresses which occur as a consequence.

A number of products found in our daily lives come from mechanical recycling processes, such as grocery bags, pipes, gutters, window and door profiles, shutters and blinds, etc. The quality is the main issue when dealing with mechanically recycled products. The industrial PSW generated in manufacturing, processing, and distribution of plastic products is well suited for the use as a raw material for mechanical recycling due to the clear separation of different types of resins, the low level of dirt and impurities present, and their availability in large quantities.

Existing plants and technologies applied in mechanical recycling

Recycling IPW via mechanical means involves a number of treatments and preparation steps to be considered. Being a costly and an energy intense process, mechanical recyclers try to reduce these steps and working hours as much as possible. Generally, the first step in mechanical recycling involves size reduction of the plastic to a more suitable form (pellets, powder or flakes). This is usually achieved by milling, grinding or shredding. The most general scheme was described in the steps involved are usually the following:

1. Cutting/shredding: Large plastic parts are cut by shear or saw for further processing into chopped small flakes.
2. Contaminant separation: Paper, dust and other forms of impurities are separated from plastic usually in a cyclone.
3. Floating: Different types of plastic flakes are separated in floating tank according to their density.
4. Milling: Separate, single-polymer plastics are milled together. This step is usually taken as a first step with many recyclers around the world.
5. Washing and drying: This step refers to the pre-washing stage (beginning of the washing line). The actual plastic washing process occurs afterwards if further treatment is required. Both washing stages are executed with water. Chemical washing is also employed in certain cases (mainly for glue removal from plastic), where caustic soda and surfactants are used.
6. Agglutination: The product is gathered and collected either to be stored and sold later on after the addition of pigments and additives, or sent for further processing.
7. Extrusion: The plastic is extruded to strands and then pelletized to produce a single polymer plastic.
8. Quenching: Involves water-cooling the plastic by water to be granulated and sold as a final product.

1.1.2 Chemical recycling:

Chemical (tertiary) recycling is a term used to refer to advanced technology processes which convert plastic materials into smaller molecules, usually liquids or gases, which are suitable for use as a feedstock for the production of new petrochemicals and plastics. The term chemical is used, due to the fact that an alteration is bound to occur to the chemical structure of the polymer. Products of chemical recycling have proven to be useful as fuel.

The technology behind its success is the depolymerization processes that can result in a very profitable and sustainable industrial scheme, providing a high product yield and minimum waste. Under the category of chemical recycling advanced process (similar to those employed in the petrochemical industry) appear e.g. pyrolysis, gasification, liquid–gas hydrogenation, viscosity breaking, steam or catalytic cracking and the use of PSW as a reducing agent in blast furnaces.

1.1.2.1 Thermolysis:

Pyrolysis: (thermal cracking of polymers in inert atmospheres) Thermolysis is the treatment of PSW in the presence of heat under controlled temperatures without catalysts. Thermolysis processes can be divided into advanced thermo chemical or pyrolysis (thermal cracking in an inert atmosphere), gasification (in the sub-stoichiometric presence of air usually leading to CO and CO2 production) and hydrogenation (hydrocracking).

Pyrolysis provides a number of other advantages, such as :

1. Operational advantages: Operational advantages could be described by the utilization of residual output of char used as a fuel or as a feedstock for other petrochemical processes. An additional operational benefit is that pyrolysis requires no flue gas clean up as flue gas produced is mostly treated prior to utilization.
2. Environmental advantages: Environmentally, pyrolysis provides an alternative solution to landfilling and reduces greenhouse gas (GHGs) and CO2 emissions.
3. Financial benefits: Financially, pyrolysis produces a high calorific value fuel that could be easily marketed and used in gas engines to produce electricity and heat.
4. Several obstacles and disadvantages do exist for pyrolysis, mainly the handling of char produced (Ciliz et al., 2004) and treatment of the final fuel

produced if specific products are desired. In addition, there is not a sufficient understanding of the underlying reaction pathways, which has prevented a quantitative prediction of the full product distribution.

1.1.2.2 Gasification:

Declining landfill space and high incineration cost of MSW encourage research and development in thermolysis technologies, which gasification fall into, producing fuels or combustible gases from waste. Air in this process is used as a gasification agent, which demonstrates a number of advantages.

The main advantage of using air instead of O_2 alone is to simplify the process and reduce the cost. But a disadvantage is the presence of (inert) N_2 in air which causes a reduction in the calorific value of resulting fuels due to the dilution effect on fuel gases. Hence, steam is introduced in a stoichiometric ratio to reduce the N_2 presence.

Several types of gasification processes have already been developed and reported. Their practical performance data, however, have not necessarily been satisfactory for universal application. A significant amount of char is always produced in gasification which needs to be further processed and/or burnt.

2. LITERATURE SURVEY

R.P. Singh et al.2011 [1] A critical review of known MSW management practices/processes in Indian scenario, which will give an idea to investors about the market potential, the maturity of the practicing technologies, and the environmental and economic aspects was also evaluated with its advantages and disadvantages.

Population range (million)	No of cities surveyed	Compostable matter	Metal	Inert material	Paper	Rubber, leather and synthetics	Glass
0.1 -0.5	12	44.57	0.33	43.59	2.91	0.78	0.56
0.5 -1.0	15	40.04	0.32	48.38	2.95	0.73	0.56
1.0-2.0	9	38.95	0.49	44.73	4.71	0.71	0.46
2.0-5.0	3	56.57	0.59	40.07	3.18	0.48	0.48
5.0 above	4	30.84	0.8	53.9	6.43	0.28	0.94

Table 2.1: Physical characteristics of MSW in Indian cities

The incineration process is separated into three main parts: incineration, energy recovery and air pollution control. Emissions from the incineration of MSW along with other municipal wastes contain air pollutants (SOx, NOx, COx). Thus the incineration of MSW may result in air pollution, unless the incinerators are well equipped with appropriate pollutant control accessories.

Pyrolysis/gasification: Production of fuel gas/oil, which can be used for a variety of applications. Compared to incineration, control of atmospheric pollution can be dealt with in a superior way, in techno-economic sense.

Chemical conversion (incineration, pyrolysis/gasification) for energy recovery as heat must first be supplied to remove moisture. For determination of the energy recovery potential and the suitability of waste treatment via biochemical or thermo-chemical conversion technologies the important chemical parameters to be considered includes volatile solids, fixed carbon content, inerts, calorific value (CV), C/N ratio (carbon/nitrogen ratio), and toxicity. Usually 100 tons of raw MSW with 50–60% organic matter can generate about 1–1.5 MW power, depending upon the waste characteristics. The desirable range of important waste parameters for technical viability of energy recovery through different treatment routes

Hossam A. Gabbaretal.2017 [2]

This paper discusses the latest analysis in solid waste thermal treatment methods including life cycle assessment (LCA), process systems, economic and energy analysis. The MSW collected by municipalities such as paper, plastics, organic materials, glass, metals, food, leather and rubber can be utilized, via primary treatment methods which are mainly pyrolysis, gasification and combined pyrolysis gasification (P-G) cycles to generate thermal energy or electricity.

The importance of solid waste treatment comes from its potential to convert waste into several sources of energy or fuels such as gasoline, syngas or diesel, eliminate waste, and reduce CO2 emissions. The process systems are explained in terms of process stages, carrier gases, operating pressures and temperatures, end products and reaction residence time.

	Incineration	Gasification	Pyrolysis
Process Description	Convert MSW in a combustion process to high temperature flue gas CO_2 and H_2O in excess oxygen	Convert MSW to HHV syngas which consists mainly of CO, H_2 and CH_4	MSW thermal cracking in absence of oxygen to hydrocarbon gases, liquids and wax
Reaction environment	Oxidizing reaction	Air, pure oxygen, steam	Nitrogen gas or any inert gas
Reactant gas	Excess Air	Air, O_2, Steam	No reactant gas
Temperature	850℃ to 1200℃	550 ℃to 900 ℃	500℃to 800℃
Pressure range	Atmospheric	Atmospheric	Over atmospheric
End-products	CO_2, H_2O	CO,H_2O ,H_2,CH_4	CO, H_2, CH_4 hydrocarbon liquids
Undesir eeffluents	SO_2, nitric oxides, HCl	H_2S, Sulpher oxide, NH_3,HCN tar	H_2S, HCl, NH_3, HCN, tar.
Essential installations	Air pollution control	Syngas cleaning is required	No treatment is needed

Table 2.2: Main characteristics MSW thermo-chemical treatment methods

In terms of life cycle assessment, pyrolysis shows highest NO2 emissions but showed acceptable results for SO2, CO and HCl. Pyrolysis-gasification (P-G) showed lowest NO2, SO2, CO emissions and acceptable HCl. Gasification shows acceptable NO2, SO2 but highest CO and HCl emissions. Overall, combined pyrolysis – gasification shows the best optimized process with low environmental emissions.

A. Adrados et al 2012[3]

Pyrolysis may be an alternative for the reclamation of rejected streams of waste from sorting plants where packing and packaging plastic waste is separated and classified. These rejected streams consist of many different materials (e.g., polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyethylene terephthalate (PET), acrylonitrile butadiene styrene (ABS), aluminum, tetra-brik, and film) for which an attempt at complete separation is not technically possible or economically viable, and they are typically sent to landfills or incinerators.

For this study, a simulated plastic mixture and a real waste sample from a sorting plant were pyrolyzed using a non-stirred semi-batch reactor. Red mud, a byproduct of the aluminum industry, was used as a catalyst. Despite the fact that the samples had a similar volume of material, there were noteworthy differences in the pyrolysis yields. The real waste sample resulted, after pyrolysis, in higher gas and solid yields and consequently produced less liquid. There were also significant differences noted in the compositions of the compared pyrolysis products.

Shafferina Dayana Anuar Sharuddin et al 2016[4]

This review has provided concise summary of plastic pyrolysis for each type and a discussion of the main affecting parameters to optimize liquid oil yield. Based on the studies on literatures, pyrolysis process was chosen by most researchers because of its potential to convert the most energy from plastic waste to valuable liquid oil, gaseous and char. Therefore, it is the best alternative for plastic waste conversion and also economical in terms of operation.

The flexibility that it provides in terms of product preference could be achieved by adjusting the parameters accordingly. The pyrolysis could be done in both thermal and catalytic process.

The sustainability of the process is unquestionable since the amount of plastic wastes available in every country is reaching millions of tons. With the pyrolysis method, the waste management becomes more efficient, less capacity of landfill needed, less pollution and also cost effective. Moreover, with the existence of pyrolysis method to decompose plastic into valuable energy fuel, the dependence on fossil fuel as the non-renewable energy can be reduced and this solves the rise in energy demand.

A. Lopez et al.2011 [5]

Pyrolysis is an attractive alternative for recycling mixed plastic waste Conversions to liquids and gases as high as 99 wt.% are obtained. The liquids may be used as high HHV alternative fuels or as a source of valuable chemicals, such as styrene or toluene. Gases can be used to supply the energetic demand of the process and the surplus may be used for additional power generation, which indicates that plastic waste pyrolysis is an energetically sustainable process.

As pyrolysis temperature is raised, gas yields significantly increase to the detriment of liquid yields. 460 ◦C is the lower temperature at which total conversion is achieved but the liquids are extremely viscous (semi-solid at room temperature) and difficult to handle. 500 ◦C was established as the optimal temperature for plastic waste pyrolysis, in terms of both conversion and quality of the pyrolysis liquids. Reaction time in the range 15–30 min is enough to achieve total conversion of the plastic waste, Moisture and ash content and elemental analysis is in wt%.

SR. NO.	RESULTS	Units
Moisture	0.1	%
Ash	0	%
C	84.7	%
H	12.5	%
N	<0.1	%
Cl	1.1	%
Others	1.5	%
H/C ratio	1.8	-
HHV	43.9	(MJ/kg)

Table 2.3: Characterization of Waste By Ultimate and Proximate analysis.

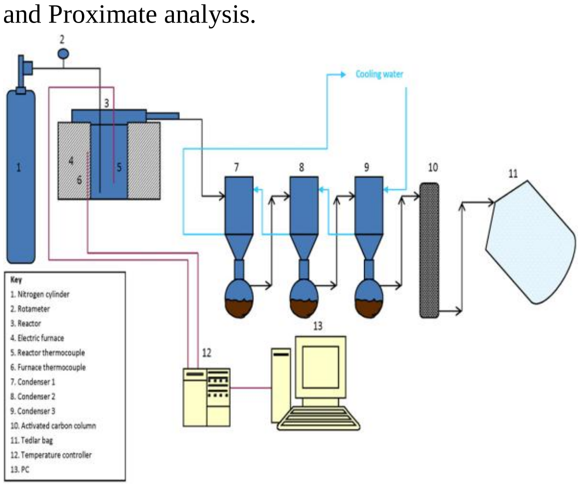

Figure2.1: Flow sheet of the experimental set-up used.

As it has been mentioned before, 500 ◦C was considered the most appropriate temperature to carry out the experiments devoted to study the influence of time on plastic wastes pyrolysis. The effect of reaction time was explored in the range 0–120 min; the reaction time was counted from the moment the experiment temperature was reached.

A.K. Panda et al.2010 [6]

- Chemical recycling
- Depolymerisation
- Partial oxidation
- Cracking/pyrolysis
- Hydrocracking
- Thermal cracking.
- Catalytic cracking/pyrolysis

The utility of plastics cannot be reduced due to its wide field applications and thus 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 analysis of different methods described in previous section indicate mechanical recycling is widely adapted method by different countries, however gradually the catalytic pyrolysis of plastic to fuel is gaining momentum and being adopted in different countries recently due to its efficiency over other process in all respects.

A. Aboulkas et al 2010[7]

The kinetics of the thermal degradation of HDPE, LDPE and PP was accurately determined from a series of experiments at four heating rates (2, 10, 20 and 50 K/min). The activation energy was calculated by the isoconversional methods (Friedman, Kissinger– Akahira–Sunose, Flynn–Wall–Ozawa) without previous assumption regarding the conversion model fulfilled by the reaction.

The activation energy was found practically constant in the 0.1–0.9 conversion range, this suggesting that the pyrolysis was a single step process with an activation energy of 238 247 kJ/mol for HDPE, 215–221 kJ/mol for LDPE and 179–188 kJ/mol for PP. The corresponding kinetic parameters were calculated to well interpret the relationship between the plastics. Finally, Coats–Redfern and Criado methods were successfully utilized to predict the reaction mechanism of thermal degradation of plastics. The pyrolysis reaction models of HDPE and

LDPE can be described by ‘‘Contracting Sphere” model, whereas that of PP by ‘‘Contracting Cylinder” model.

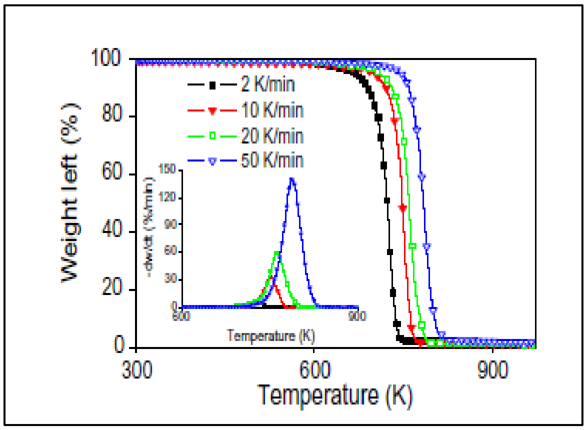

Figure 2.2: TG curves of HDPE at different heating rates. Inset: corresponding DTG curves.

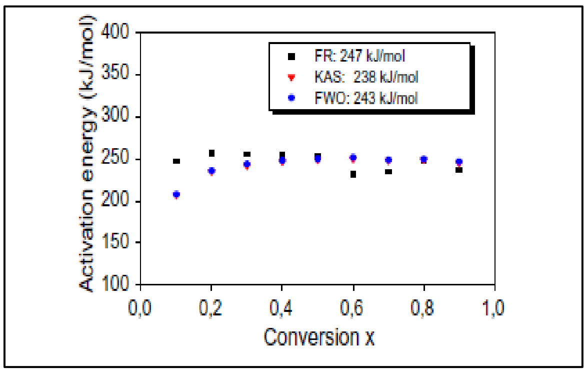

Figure 2.3: The dependence of activation energy on the conversion (x) for thermal degradation of HDPE according to FR, KAS and FWO methods.

3.CONCLUSION

This paper concludes the brief introduction about various papers described here.

The literature review carried out presents pathways to treat plastics in addition to emissions resulting from respective thermochemical treatment. Pyrolysis due its lesser energy investment and economics with value added products from process makes it as an attractive option to treat waste plastics. The sustainability of process and decreasing landfill capacity makes the process advantageous with lesser dependency to be made on fossil fuels. Fuels produced from the process are of superior quality with an option for plastic waste management. For design of pyrolysis process first step which needs to be taken into account is intrinsic kinetics, which in addition to heat mass and momentum transfer effects will ultimately determine the degradation of plastics in the reactor. The determination of kinetics is of extreme importance and hence kinetics plastic degradation as reported by various studies was reviewed. Various types of plastics taken into consideration were HDPE, LDPE, PP, PS, PTFE under non-isothermal and isothermal conditions. The degradation model followed in the decomposition path is extensively reviewed

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