Plastic Waste to Energy by Advance Pyrolysis Techniques

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ABSTRACT

Land filling and Direct combustion of plastic waste are eco-damaging disposal technique. However, there are some other waste management techniques exist such as mechanical recycling and chemical recycling. Since waste plastic is an organic substance can be transformed into some value added product without having a considerable impact on world ecology and global climate. Gasification, pyrolysis are thermochemical conversion processes which fall into the category of chemical recycling process have tendency to transform these waste plastics into useful fuels and valuable feedstock's. Pyrolysis has been the area of intense scientific research produces gaseous and liquid fuels together with solid residue and char. Thermal pyrolysis produces product of inferior quality that cannot be directly used in internal combustion engine. Catalytic pyrolysis increases selectivity towards final product, reduces temperature requirement and reaction time. On the other hand plasma pyrolysis which is well known current method can handle a very complex plastic waste, works on zero emission philosophy. Microwave pyrolysis which is one of the advance technique provide better control over temperature, fast heating and and uniform temperature distribution. The present paper deals with such advance pyrolysis techniques.

Keywords: Plastic waste, Pyrolysis, High-density polyethylene (HDPE), Polyvinylchloride (PVC), Polyethylene terephthalate (PET), Chemical Recycling, Polystyrene (PS), Feedstock.

1. INTRODUCTION

Waste Plastics which are organic substances have large impact on environment due to their non biodegradability, can be transformed into liquid and gaseous fuel for internal combustion engine, boiler, fuel cells etc. There are different plastic waste management techniques exist such as land filling, direct burning (incineration), mechanical recycling and chemical recycling. Chemical recycling is the most attractive method in accordance with principle of sustainable development, and is also called feedstock or tertiary recycling [1]. The global consumption of plastics was reported to be 230MT in 2005 of which 47.5MT were produced in Europe (25 European union countries + Norway and Switzerland) [2]. Europeans and Americans are the great consumers of plastic of about 100kg/capita/annum with the potential to rise 140kg/capita/annum by 2012 scenario [3]. In India the consumption of plastic has increased from 4000 tone/year (t/y) in 1992 to 5 MT/y in 2005. The per capita plastic consumption is 4kg/y. Asian region (excluding Japan) is the biggest developing region, where per capita plastic consumption was only 20kg by 2008, but it is expected to increase by approximately 16kg by 2015[4]. The worldwide production fall back in 2008 to 245MT from 260MT in 2007. Europe was the major producer of 25% of global total in 2008.

As it can be seen in figure 1, North Atlantic Free Trade Agreement (NAFTA) states are the biggest demander for primary plastic products. Therefore, it can be deduced, that NAFTA states, followed by the West European countries, are also the biggest plastics producer.

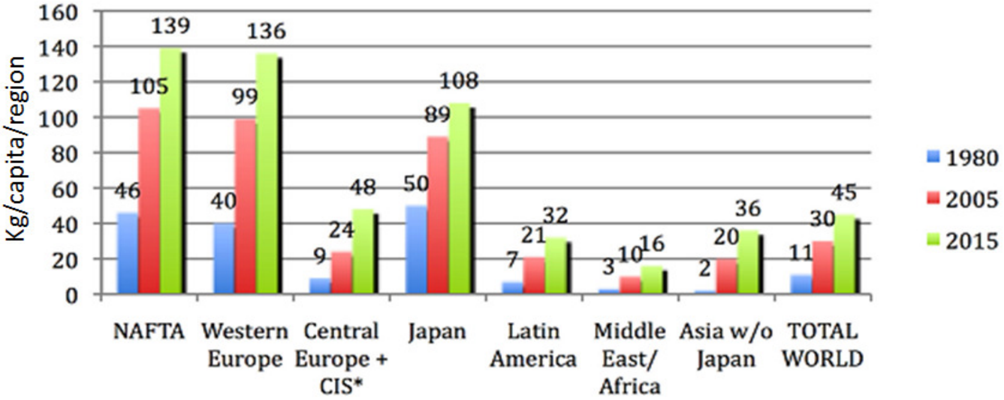

Fig. 1 Annual plastics demand by converters in kg per capita per region for the years given: 1980, 2005 and 2015[4]

Pyrolysis which falls into the category of chemical recycling process is an endothermic, irreversible, high temperature phenomenon which transforms organic material into its smaller constituents. Catalytic pyrolysis which represents an area of intense scientific and technological research has a great potential to absorb large volume of plastic waste. Plasma pyrolysis which works on zero emission philosophy can use various types of plastic waste. Pyrolysis by microwave is a recent technique offering variety of advantages such as even heating of moving materials etc, has been highlighted in the present paper.

2. ADVANCE PYROLYSIS TECHNIQUES OF PLASTIC WASTES

Catalytic cracking of plastic waste to fuel. Thermal (conventional) cracking provide high product distribution, polymers require high temperature to breakdown in low molecular weight products it also requires high reaction time. These are some problems because of that catalytic cracking comes into existence. Less temperature and less time consumption and narrower product distribution makes the catalytic process more economical and attractive. It also increases reaction rate necessitate smaller reactor volume. Catalytic cracking results in production of branched and cyclic molecules and aromatics [5]. Improved selectivity and quality of product are the main features of catalytic cracking [6, 7, 8]. The rate of reaction, distribution of products, and type of upgrading reaction can be altered by the use of heterogeneous catalyst [9, 10]. The aim of catalyst is hydrogenation of alkenes, the removal of hetro atoms such as oxygen, nitrogen and halogens [11]. Since the use of expensive catalyst may condition the economy of process and hence catalytic cracking process will be advantageous when catalyst will have zero cost.

Plasma Pyrolysis. Plasma pyrolysis integrates thermochemical properties of plasma with pyrolysis process, which takes place in absence or negligible amount of oxygen. Plasma pyrolysis use extremely high temperatures (2000-10000K) of plasma arc to decompose waste material completely into simple molecule. In plasma pyrolysis firstly, the plastic waste feed into the primary chamber at 850°Cthrough a feeder. The waste materials dissociates into CO, H_2, CH_4, higher hydrocarbons etc. Induced draft fan drains the pyrolysis waste gases as well as plastic waste into the secondary chamber, where these gases are combusted in the presence of air. The inflammable gases are ignited with high voltage spark. The secondary chamber temperature is maintained around 1050°C [12]. The technology has demonstrated that the emission of toxic compounds such as dioxins and furans were very less as compared to incineration process. Plasma pyrolysis of plastic waste provides a large quantity of higher hydrocarbons gases.

2.3 Microwave pyrolysis. Microwave pyrolysis is relatively new field. It provides more even distribution of heat and better control over the heating process. Microwave pyrolysis not only overcome the disadvantage of conventional pyrolysis such as slow heating and feedstock shredding but also improves quality of final pyrolysis product and same time the energy [13]. In contrast with conventional heating mechanism, where energy is first converted to heat and then transferred along temperature gradients from the surface to the core of the material, microwave induced heat at molecular level by direct conversion of electromagnetic field into heat [14]. However, for microwave pyrolysis knowing dielectric and conductive properties of plastic waste has important role. Thermoplastics (with the exception of nylons) normally have very high dielectric constants and low loss factors and are known as ‘transparent’ to microwaves. Therefore, they have not been thought of as candidates for microwave processing in the past [15]. The problem of poor thermal conductivity of polymer is overwhelmed and a simpler apparatus may be employed like static bed reactors, the reaction time can be reduced from hours to few minutes [14]. As compared to conventional pyrolysis, microwave pyrolysis provides fast heating, saves time and energy. Thermal conductivity of polymer does not play any role in microwave pyrolysis. However, it requires only electrical power as an input energy source.

3. RECENT TRENDS OF ADVANCE PYROLYSIS TECHNIQUES FOR PLASTIC WASTES

Plasma Pyrolysis. It was observed that using an induction coupled plasma (ICP) reactor combined with plasma plate power (10-20KVA) followed by a rapid quenching (1000K/s). Waste polypropylene (PP) can be deploymerized into propylene. Process is characterized by a high heating rate of feed power and rapid quenching of product vapor to terminate the secondary transformation of product. PP is converted to gases product (78%), mainly propylene [16]. The typical composition of plasma pyrolysis gases obtained in different experiments is shown in table-6. Gases mainly composed of H_2, CO, C_2H_2, and CH_4 & C_2H_4.

Table 2: Example of thermal plasma pyrolysis treatment (wt% on the original material basis; blank entry means data not available)

Feed	Plasma Torch	Gas product distribution (wt %)							Ref
		H_2	CO	CH_4	C_2H_2	C_2H_4	C_3H_6	CO_2	
PP	DC plasma	18.3	0.5	2.4	6.3	0.5		0.06	[17]
PP	ICP			2.6		1.7	93.7		[18]
PE	ICP			5.6	5.7	22.2	53.4		[19]

Pollutant gases, such as SO_2 and NO_x are found in low concentrations [20]. Pyrolysis of polyethylene provides more than 90% combustible gases. When 100% polyethylene (PE) was fed, the gases generated are H_2 (41.4%), CO (15.3%), CH_4(17.7%), CO_2(1.6%), higher hydrocarbons(16.7%) and N_2(7.3%) by volume are obtained[21]. In ICP pyrolysis of PE, the gases products obtained were mostly mixtures of propylene and ethylene together with smaller amounts of other hydrocarbons. Ethylene concentration ranged from 2.5% to 24%, propylene concentration propylene concentration ranged from52% to 92% and amount of solid residue collected ranged from 15% to 50% by weight of total polymeric powder fed into the reactor [22].

Microwave Pyrolysis. There has been few literature on microwave pyrolysis of plastics. Microwave pyrolysis, invention is intended to apply the principle of wave physics including microwave and radio frequency irradiation and or electron beam bombardment in order to crack hydrocarbons and waste plastics into smaller molecular weight entities. The heating of materials by microwave is described by following power absorption equation

$$P = kfE^2\varepsilon \tan\delta$$

Where P is the dissipation in W/cm^3, k is constant equal to 55.61×10-14, f is the applied frequency in HZ, E is the electric field in V/cm, ε is the dielectric constant and tanδ is the dielectric loss tangent. Cambridge University has conducted experiment for plastics pyrolysis by using microwave furnace heating implemented on a lab scale, modified microwave furnace system which is represented by the schematic in fig. 2. Below 50 grams of high density polyethylene (HDPE) of average density 954kg/m^3 and diameter 3mm was mixed with a kilogram of particulate carbon. The furnace (maximum operating power: 5kW) operated at 1250W (2.45 GHZ, for 500°C) for 350 seconds upon the addition of plastics, the thermocouple measuring the temperature of degrading plastics reported a system temperature of 500°C[23]. Fig. 3 shows the product of microwave pyrolysis of HDPE with time at a temperature of 500°C and 600°C.

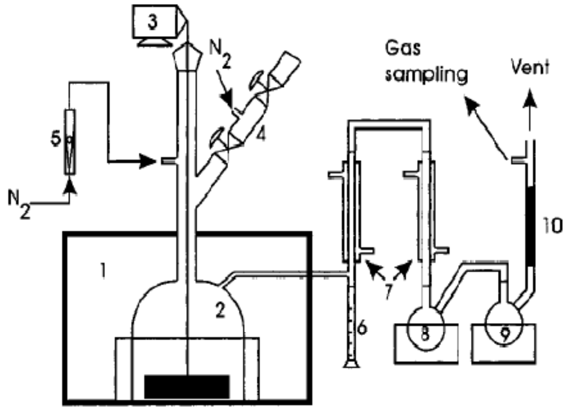

Fig. 2 Schematic of MWP Setup [22].

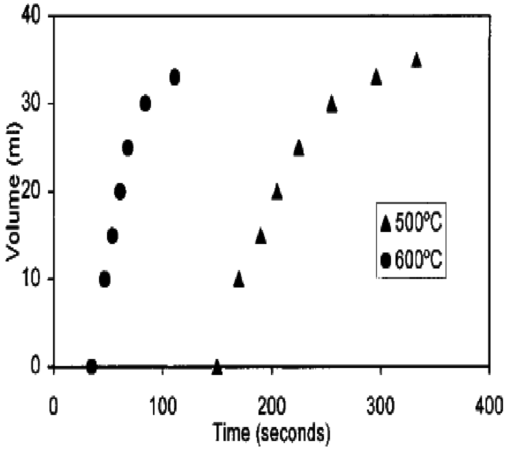

Fig. 3 Cumulative Yield of Products for MWP of 50 grams of HDPE over 500°C and 600°C [22].

It was found that reactor temperature had the greatest effect on rate of reaction/decomposition. In microwave pyrolysis the thermal degradation of HDPE requires HDPE flakes mixed with a microwave absorbent. Different microwave power gives completely different products. HDPE when heated to a temperature below 730°C it mainly forms a wax (a semi-solid product) and a liquid. Together with the increasing of temperature the amount of wax decreases in advantage to liquid and gas products. At 730°C there is no formation of wax, just liquid and gas [24]. Over 800°C the conversion of polymer in gases is almost total: 91.2% at 850°C [25]. The gas is composed of H_2, CH_4, C_2H_6, C_2H_4, C_3H_6 and C_3H_8. The liquid and wax are made of alkanes, from C_{11} to C_{57}, and their equivalent 1-alkene and 1,3-dialkene[26]. Polyvinylchloride (PVC) cracking by microwave follows same procedure as conventional (thermal) cracking. The thermal degradation of PVC taken place in two-steps: dehydrochlorintion followed by residual chain cracking. The polymer quickly eliminates HCl that has been absorbed in NaOH traps after the collecting flasks. The main product of microwave pyrolysis of PVC present in liquid fraction are aromatic compounds, which are Benzene, Toluene, 1,3-dimethyle-benzene, 1,4-dimethylebenzene, styrene, 1,2-dimmethylbenzene, Naphthalene[27]. In the past microwave pyrolysis of Polystyrene (PS) was carried out using metals like iron as antenna to produce useful hydrocarbons. It was found that microwave pyrolysis provide more even distribution of heat and better control over the heating process than conventional technique.

4. CONCLUSION

- Essentially, microwave-assisted pyrolysis is a novel approach which offers internal heating of plastic waste, the yields and product properties are controlled by microwave power. The oils produced under this technique, offer less hazardous compounds and produce a greater number of chemicals which are of interest to industry, than those obtained under conventional pyrolysis.
- Silicon carbide is recommended as a microwave absorbent over carbon due to its electrical and thermal physical properties, such as its higher loss factor making it able to absorb microwaves more efficiently, its higher density meaning it creates less dust in the reactor, and higher thermal conductivity to aid in the heat transfer within the sample mixture.
- Plasma pyrolysis technology can safely destroy chlorinated as well as multi-layer plastic wastes. Plasma pyrolysis can be used to destroy metalized plastics, polyethylene mixed with polyvinylchloride and multi layer plastic in an environmental friendly manner.

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