Fuel 174 (2016) 164–171

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Time and temperature depended fuel gas generation from pyrolysis of real world municipal plastic waste

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ARTICLE INFO

Article history:
Received 20 July 2015
Received in revised form 16 December 2015
Accepted 13 January 2016
Available online 28 January 2016

Keywords:
Municipal plastic waste
Pyrolysis
Fuel
Hydrocarbons

ABSTRACT

On a large scale, amount of pyrolytic gas generated and their components has a very important role in product recovery in form of energy. The obtained gases having HHV can be utilized for generation of power or can be utilized in the process itself to reduce the input energy and helps to become self sustainable process. In the present study, real world municipal plastic waste mainly comprising of polyethylene (low and high density), polypropylene, polystyrene and polyethylene terephthalate were pyrolyzed at different temperatures, ranging 450–600 °C with a sample mass of 200 g to create an appropriate real blend environment. The non-condensable gaseous product generation profile was studied along with heat transfer profile in reactor. The effect and formation of gaseous products was explained based on experimental investigation which shows an increase in H_2 on increasing the temperature with decrease in low molecular weight hydrocarbons. In addition, the identification of non-condensable gaseous components was done using gas chromatography. Effect of residence time was strong at higher temperature process conditions producing heavier hydrocarbons in gas; and in oil as wax. Increase in operating temperature increased the concentration of H_2 whereas no effect on formation of CO and CO_2 was observed. Recovery time of non-condensable gases was less at higher temperature whereas yield increases on increasing the operating temperature. Residence time of volatiles in reactor affected the formation of hydrocarbons like ethylene, propane and n-butane.

1. Introduction

Increase in energy demand and depletion of conventional sources of energy like fossil fuel reservoirs, forces us to find an alternative fuel which is cheaper and environment friendly or to allow use of secondary fuels in place of primary fuels or with primary fuels to decrease the consumption of fossil fuels. Plastics, one of the most commonly used material in day-to-day life could be used as an alternative source of energy after its useful life as it derived from petroleum products [1]. Rapid urbanization and economic development and convenience in use and manufacturing, the world plastic production increased since it was first commercially manufactured from 1.5 million tonnes (MT) in 1950 to 245MT in 2008 [2,3]. The production of plastic increased on an average of 10% every year on global basis since 1950 as continuous innovation and research for better product in the field occurred. The plastic possesses excellent properties like light weight and non-corrosive nature due to which metal and wood industries were highly affected [4,5].

Plastic waste is the third largest contributor to municipal solid waste (MSW) after food and paper [6]. In USA 32 MT of plastic waste was generated in 2012, out of which only 9% of total plastic waste generated in 2012 was recovered for recycling [7]. High consumption of plastic leads to large mass disposal as plastic waste represents around 20–30% by volume and 10–12% by weight in MSW [8]. Developing countries in Asia like India, China, Malaysia, and Singapore have a higher potential for growth; having a per capita consumption of 20 kg/year. In India, average virgin plastic consumption was 3 kg/year (5 kg with recycle material) in 2000–2001 from 0.8 kg/year (2 kg with recycle material) in 1998–1999. The consumption of plastic in India is one fourth of the world average whereas china consumes about one sixth of world average plastic production [9,10]. Plastic waste generated in India was 2.38 Million Tonnes (MT) in 2000–2001 and estimated to raise about 8 MT by 2008 [9]. According to a report in 2013, India generates 5.6 million MT of plastic waste annually, with Delhi generating the most of at municipalities at 689.5 MT every day out of which about 60% was recycled [11].

Environmental pollution due to plastic waste is occurring as a global phenomenon today. Recycling waste plastic into re-usable plastic products is a conventional strategy followed to address this

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http://dx.doi.org/10.1016/j.fuel.2016.01.049
0016-2361/

issue for years [12]. High plastic consumption and low average life had increased the difficulties for disposal of plastic waste and emerged as an important environment challenge and its recycling facing road blocks due to their non-degradable nature [13]. Recycling and reuse of plastic is gaining importance as a sustainable method for plastic waste disposal [14]. Petroleum based plastic waste can be converted into reusable products like gasoline and heavy oils by recycling and refining for energy/chemical source from thermal treatment/combustion [15–17]. As an alternative to combustion and gasification, pyrolysis of plastic waste has gained importance because of having better advantages toward environmental pollution. Absence of oxygenated compounds or oxygen in the process resists the formation of dioxins which are formed at higher temperatures. In combustion/incineration or gasification, oxygen available at higher temperature reacts with the product to form oxygenated compounds and presence of nitrogen confirms the formation of nitrogenous compounds which are harmful to the environment. Being an inert atmosphere (free from oxygen) and low temperature process, pyrolysis does not allow forming dioxins, as well as reduces the carbon footprints by reducing the emission of carbon monoxide (CO) and carbon dioxide (CO_2) [18–21].

The pyrolysis process is thermo-chemical degradation reaction operated at high temperature ranging from 400–900 °C in an inert atmosphere. On heating above degradation temperature, those high-molecular chains are lysed to stabile low-molecular products and solid residue [22]. Products like gas, oil/wax, and char were obtained as a result of the process whose composition and yield depends on plastic type, reactor type, and process condition particularly reaction temperature and heating rate [23–27]. Influence of catalyst was also studied and observed by many researchers for obtaining high percentage of oil phase product from the process [28–35]. Decomposition reactions during degradation of mixed plastic waste were very difficult to determine whereas some researchers have determine the individual kinetics for different type of plastic waste [36–41]. In addition, radical chain mechanism in liquid phase is used to determine the degradation of polyethylene (PE) and polypropylene (PP) mixture and a model was proposed [36]. Later on a kinetic model was proposed for mixture of PE and polystyrene (PS) to determine the effect of mixing of these two and synergetic effects were concluded [37]. Model for mixture of polyethylene terephthalate (PET), PP, and low density PE (LDPE) were also proposed based on binary and tertiary degradation reaction kinetics mechanism to determine the mixed behaviour of the material in mixture for obtaining fuel grade oil [38–42].

Polymer degradation in their individual form and simple mixtures were well described in literature while real world municipal plastic waste (MPW) was analysed by very few researchers and a very less information is available [17,29,30,43–47]. It was also analysed that overall degradation rate of MPW was greater than the combined degradation rate of the individual component of plastic waste [41]. In addition, lot of research has been done considering to obtain fuel grade oil and gases whereas a very low information is present regarding the gas generation during the process and mechanism and their behaviour with respect to temperature and time. Most of the research work available focuses on oil analysis as it is major product while a very less importance is given to gas generated during the process as an enormous amount was generated on a large scale which cannot be neglected and has an important role in product recovery in form of energy. The obtained gases having high heating value (HHV) which can be utilized for generation of power or can be utilized in the process itself to reduce the input energy sources and helps to become self sustainable process.

2. Material and methods

2.1. Raw materials

Post consumer, real world MPW was collected from MSW from different location in Durgapur (West Bengal, India), were taken as sample for the experiment. Wastes like PP, PET, PS, high density PE (HDPE), LDPE, Polyamide, Polycarbonate (CD's), labelling paper and inert were determined in the waste plastic samples. Polyvinyl chloride (PVC) was excluded from the experimental sample material to remove presence of chlorine in the products forming hydrochloric acid (HCl) causing damage to the reactor. The waste plastic were shredded into small flakes/chips of size ranging from 1 to 3 cm. Non-washed, dried material (Fig. 1) obtained after shredding was sieved to remove the sand particles and was used as feed to the reactor which is shown in Fig. 2. The MPW was categorised into its component to determine the proportion of components which are obtained as 58.8% Polyethylene (HDPE and LDPE), 26.9% PP, 8.7% PS and 5.6% PET. MPW used by other researchers was also analysed and is presented in Table 1. The sample mass used in the reactor was 200 g. High amount of mass is important for heterogeneous sample to ensure a proper representative of mixture of plastic waste and well representation of industrial processes. Proximate and ultimate analysis was done and is presented in Table 2.

2.2. Experimental setup

The experimental setup is a single step pyrolysis reactor comprising of electrically heating coil to provide heat to the reactor equipped with oil collection unit and gas pressure measuring section shown in Fig. 2. The process is batch type process, having a handling capacity up to 400 g by weight and a pressure of 2 atmospheres. Programmable temperature controller controls the temperature of the reactor. A maximum heating rate of 30 °C min^{-1} can be established for the process. The products obtained in the process in the form of volatiles were removed by gas pressure difference and passed through condenser and liquid proportion is recovered. Further gases were passed through ice bath and trapped in gas tank to determine the pressure variation in the process. The gas in the reservoir was released at various intervals to neglect the

Fig. 1. Plastic waste sample (shredded and sieved).