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Review

Municipal solid waste (MSW) pyrolysis for bio-fuel production: A review of effects of MSW components and catalysts

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ABSTRACT

With the realization of fossil fuels depletion, research has been started on the alternate energy sources. Biomass is a renewable energy source, from which bio-fuels can been produced. These bio-fuels are then used for power generation. Municipal solid waste (MSW) is a type of biomass which has been widely used in the production of bio-fuels. Since 1900s, studies have shown that a lot of research has been done in determining the optimum processes for producing bio-fuel through MSW. Pyrolysis is one of these processes. This process roots out various drawbacks which are present in other processes. It produces high grade pyrolysis fuel and reduces production cost. This review paper focuses on pyrolysis of MSW by using its components as a feedstock material with varying composition. The effects of interaction between different components of MSW and their heating values has been reviewed. The heating values are then compared with conventional fuels to highlight the significance of MSW pyrolysis products. The case of catalytic pyrolysis has also been reviewed and the corresponding heating values are compared to obtain high quality fuel. Moreover, a comparison has been made that how pyrolysis is an efficient process as compared to other processes.

1. Introduction

In the recent years, the imports of crude oil have been facing challenges due to rise in crude oil prices, the fluctuating political scenario in the Middle East and the unpredictability of the global oil market. The fossil fuel burning also has hazardous environmental impacts on land, water and air. The fossil fuel energy has a great potential of changing world's climate. A small climate change can adversely affect the world's agricultural production [1]. The fossil fuels' combustion produces energy and chemicals, this results in the emission of various greenhouse gases (GHGs) like carbon dioxide, nitrogen oxides and other toxic volatile compounds in the atmosphere [2]. It is concluded that the combustion of fossil fuel has a net increase of 10.65 billion tons of atmospheric carbon dioxide per year [3]. Therefore, the selection of most environment friendly fuel is the major concern over a past few decades. Due to these challenges, the use of renewable energy resources (e.g. wind, geothermal, hydropower, biomass) came into action. Among these sources, biomass, being a non-fossil fuel, holds importance as a feedstock. It helps in the mitigation of CO_2 emissions [4]. There are numerous sources of biomass including agricultural residues, woody biomass, dedicated energy crops and municipal solid waste (MSW) [5]. Because of accelerated urbanization and development of global economy, a bulk quantity of MSW has been collected and disposed of by the municipalities. Due to this drastic increase in the disposal of MSW, the need for its management is quite necessary to preserve environment. According to the census in 2011, the growth rate of MSW in China has reached 179.36 million tons and is continually rising at a rate of 8–10% each year [6]. Similarly, in 2013, about 254 million tons of trash was generated in the USA Figs. 1 and 2 show the total MSW generation rates of America before recycling.

Municipal solid waste (MSW), commonly known as trash or garbage, consists of everyday items which are used and then thrown away, such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. These materials come from houses, schools, hospitals, and industries. [7] MSW is a type of biomass which mainly consists of food waste, paper, plastics, wood, textiles, metals, and glass [8]. It is most commonly managed by an open dumping system. In this system, MSW is open to the atmosphere [9], causing severe health and environmental issues. The open landfills results in pollution in the air, land and water, due to bacteria and insects inside the tons of dumped garbage [10]. Moreover, landfill dumping has maintenance and labor issues, the transportation cost and increase in population also hinders the efficient execution of dumping in landfills. MSW, however, due to its versatile composition, stores energy in the form of chemical bonds between carbon, hydrogen and oxygen molecules [11]. These chemical bonds release vast amount of

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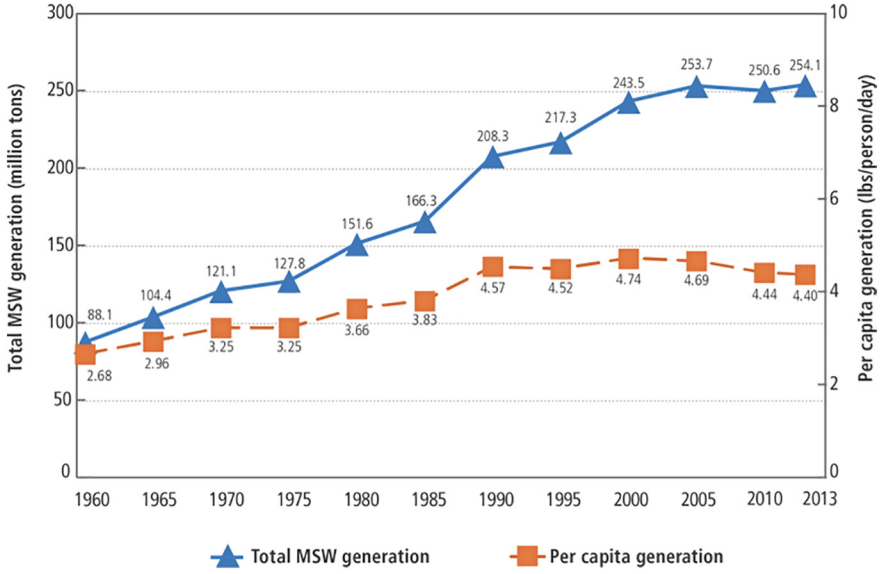

Fig. 1. MSW generation rates, 1960–2013, [7].

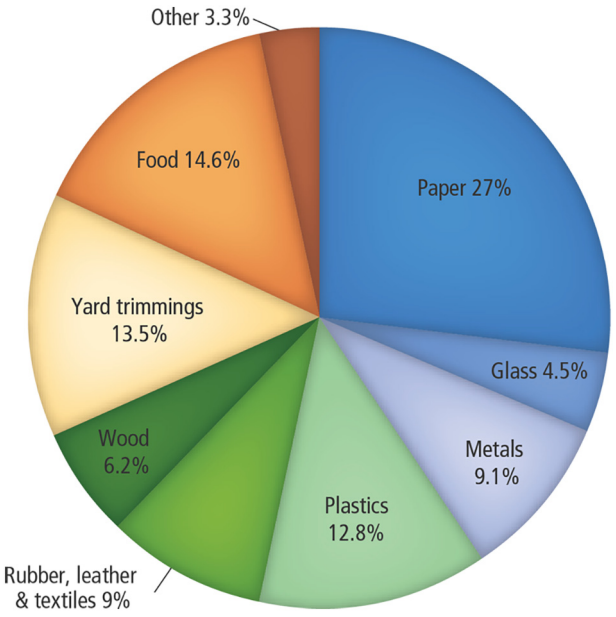

Fig. 2. Total MSW Generation (by Material), 2013 254 million tons (before recycling) [7].

energy when broken down, in order to produce gases, liquids or solids that are known as bio-fuel [12]. MSW produces heating value of around 20.57 MJ/kg [13], which can be utilized in power generation, transportation and various petrochemical industries. Therefore, MSW has a great potential to produce bio-energy.

The global MSW scenario has been reviewed in this paper to identify why the pyrolysis of MSW is necessary for the world environment. Every year, approximately 1.9 billion tons of MSW is produced worldwide. This means an annual production of 218 kg/person. The literature highlights that 19% of MSW gathered is reprocessed, 11% in used for energy regaining processes and the remainder is dumped on landfills. [14] Due to the abundance in the use of plastics, the World Bank statistics show that 8–12% of overall MSW produced in various parts of the world is plastic waste. Moreover, the estimated plastic waste production will rise to 9–13% in 2025. This will be different according to the geographical locations. [15] In Europe, measures have been taken to recover 50% of the plastic waste, however, the remainder has still been dumped causing environmental effects [16]. Similarly, according to the data collected in 2013, Sweden generated 4.5 M tons (460 kg/person) of MSW annually. In this MSW, 32% was reprocessed, 15% was applied in biological treatment and 52% was used for energy recycling [14,17]. Moreover, continuing exploring the MSW scenario in Europe, Finland has some contribution as well. The polyvinyl chloride (PVC) plastic is abundant in dry fraction of the household waste, with 90% of chlorine in it [18]. Chlorine is disastrous for health and environment, therefore, MSW needs to be processed to overcome the adverse effects. Moreover, towards the Middle Eastern side of the world, the Kingdom of Saudi Arabia (KSA) is the second biggest waste disposal country, producing approximately 6 M metric tons of plastic every year [19,20]. For Asian region, China has 81.64% of average physical combustibles and 18.36% of non-combustibles. Fig. 3 shows the percentage breakdown of the composition of MSW in Chinese cities. [21] MSW in China is not efficiently classified by the residents, it is also mixed with various food wastes. This food waste is a source of chlorine and the salt content is quite high. Due to this non-classification, the MSW characteristics in China has low calorific values and high moisture content [22]. Generally, in America and Europe the moisture in MSW (10–30% only) is less as compared to China [23]. This is due to the varying climatic conditions and life patterns. However, in Taiwan, MSW is comprised of paper (28.95%), cellulosic cloth (8.11%), yard waste (3.10%), food (23.18%), plastic (19.59%), leather and rubber (0.43%), metals (7.89%), glass (6.98%), and ceramic, earthen materials and miscellaneous (1.77%) [24]. The literature shows that newspaper is the major ingredient of waste papers of MSW [25]. The waste paper has high heating value of about 17 MJ/kg and thus has the potential to be converted to commercial fuel. So, it can be seen that recovery of MSW components is a major concern throughout the globe and the research is directed towards devising improved and cost effective technologies to solve the issue.

Thermochemical conversion processes have been adopted to produce fuel from MSW. The amount of MSW for thermal treatment has touched 921 kton/yr in 2010–2015 [26]. This review focuses on pyrolysis of MSW in order to produce fuel. Pyrolysis is the conversion of biomass (specifically MSW in this case) into liquid (bio-fuel), solid, and gaseous fractions by heating the MSW in the absence of air [27]. The main products of pyrolysis are gases, bio-oil and char. The reason for adopting pyrolysis, instead of gasification, combustion or incineration, is the production of bio-oil as well as synthesis gas and char as by-products. Another reason is the higher energy recovery efficiency as