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Review

Pyrolysis technologies for municipal solid waste: A review

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ABSTRACT

Pyrolysis has been examined as an attractive alternative to incineration for municipal solid waste (MSW) disposal that allows energy and resource recovery; however, it has seldom been applied independently with the output of pyrolysis products as end products. This review addresses the state-of-the-art of MSW pyrolysis in regards to its technologies and reactors, products and environmental impacts. In this review, first, the influence of important operating parameters such as final temperature, heating rate (HR) and residence time in the reaction zone on the pyrolysis behaviours and products is reviewed; then the pyrolysis technologies and reactors adopted in literatures and scale-up plants are evaluated. Third, the yields and main properties of the pyrolytic products from individual MSW components, refuse-derived fuel (RDF) made from MSW, and MSW are summarised. In the fourth section, in addition to emissions from pyrolysis processes, such as HCl, SO_2 and NH_3, contaminants in the products, including PCDD/F and heavy metals, are also reviewed, and available measures for improving the environmental impacts of pyrolysis are surveyed. It can be concluded that the single pyrolysis process is an effective waste-to-energy convertor but is not a guaranteed clean solution for MSW disposal. Based on this information, the prospects of applying pyrolysis technologies to dealing with MSW are evaluated and suggested.

Contents

Abbreviations: HCs, hydrocarbons; HDPE, high-density polyethylene; HHV, higher heat value, the same meaning as gross calorific value; LDPE, low-density polyethylene; LHV, lower heat value; MSW, municipal solid wastes; MPW, mixed plastic waste; PCDD/F, polychlorinated dibenzodioxins/furans; PET, polyethylene terephthalate; PP, polypropylene; PS, polystyrene; MPW, mixed plastics waste; PVC, polyvinyl chloride; RDF, refused-drive fuel; rpm, revolution per minute; TG-FTIR, thermogravimetric analysis-Fourier transform infrared spectrometer.

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1. Introduction

The treatment, management and disposal of municipal solid waste (MSW) are common concerns in every country. MSW pyrolysis is considered as an innovative alternative for treating MSW that obtains different chemicals and fuels (Schaefer, 1975; Malkow, 2004). In a pyrolysis-involved process, energy can be obtained in a cleaner way than from conventional MSW incineration plants as lower amounts of nitrogen oxides (NO_x) and sulphur oxides (SO_2) are produced as a consequence of the inert atmosphere in the pyrolysis processes and the opportunity to wash syngas before its combustion. In addition to reduced gas emissions, better quality of solid residues can be also expected from pyrolysis-involved treatment technique for MSW (Saffarzadeh et al., 2006).

In general, pyrolysis represents a process of thermal degradation of the waste in the total absence of air that produces recyclable products, including char, oil/wax and combustible gases. Pyrolysis has been used to produce charcoal from biomass for thousands of years. When applied to waste management, MSW can be turned into fuel and safely disposable substances (char, metals, etc.), and the pyrolysis process conditions can be optimised to produce either a solid char, gas or liquid/oil product, namely, a pyrolysis reactor acts as an effective waste-to-energy convertor. Compared to the conventional incineration plant which runs in capacity of kiloton per day; the scale of pyrolysis plant is more flexible. Recently, MSW pyrolysis is receiving increasing attention in small cities and towns due to the desire to prevent long-distance transportation; and it is also demanded in big cities as a distributed MSW treatment method due to the increased difficulty in finding new sites for incinerators and landfills. Generally distributed MSW treatment facilities are difficult to ensure environmental safety due to capital cost limitations; while pyrolysis plants of proper capacity with energy products output are suitable alternative when the quality of char, oil/wax and combustible gases is under fine control.

A variety of pyrolysis studies have been conducted on industrial wastes such as tyres and plastics, and several reviews have reported on the characterization of the development of pyrolysis technologies in terms of different aspects, for example, reactor development and product characterization (Sannita et al., 2012; Williams, 2013; Yang et al., 2013); conditions for oil production, oil characteristics and upgrading (Quek and Balasubramanian, 2013); the heating rate and other governing variables affecting pyrolysis process and pyrolysis products of tyres (Martínez et al., 2013); and the mechanism investigation or kinetics modelling of the pyrolysis process (Al-Salem et al., 2010; Quek and Balasubramanian, 2012). These reviews facilitate making the state-of-the-art of the development of pyrolysis of waste tyres and industrial plastics well known. As for municipal wastes, the pyrolysis of sewage sludge has been investigated for decades for liquid production, and the state-of-the-art of this technology has also been addressed in a recent review (Fonts et al., 2012). However, compared to waste types such as tyres, plastics and sewage sludge, MSW is more heterogeneous in composition and size. Currently, for MSW pyrolysis, information on technology development, characterization of products and correlated pollution is not sufficient to support technology application and system design, especially in regards to environmental impacts, which is fundamental for a single step MSW pyrolysis application.

Therefore, this work reviews pyrolysis technologies for MSW, with focus on reactors, the products from MSW pyrolysis, the pollutants involved with the MSW pyrolysis process and product applications, and the reported measures to alleviate the associated environmental impacts. The final aim is to provide essential information for understanding the pyrolysis process applied to MSW and to standardize its application as an energy converter.

2. Pyrolysis behaviours of MSW with respect to products and the influential factors

2.1. Terminology and scope

Reactions take place in a recognized pyrolysis process can be expressed as:

$$\mathrm{CxHyOz} + Q \rightarrow \mathrm{Char} + \mathrm{Liquid} + \mathrm{Gas} + \mathrm{H_2O} \tag{1}$$

where Q is the heat that needs to be input to the reactor for the reactions to take place, it includes three portions:

- Moisture vaporization Q_1

During pyrolysis the feedstock will not undergo thermal decomposition before its moisture is vaporized, and Q_1 can be calculated as:

$$Q_1 = W \times 2260,\ \mathrm{kJ\ kg^{-1}} \tag{2}$$

where W is the water content of the feedstock to the reactor, %; therefore to reduce this part of energy, MSW components with high moisture content such as food wastes, biomass are suggested to be separate before pyrolysis. In addition, in order to reduce this portion of energy a drying step is usually adopted in front of pyrolysis reactor.

- Caloric requirement of pyrolysis Q_2

The caloric requirement of the pyrolysis is calculated using the following equation (Raveendran et al., 1996):

$$Q_2 = C_{p,M}\int m_M dT + C_{p,ch}\int m_{ch} dT + C_{p,v}\int m_v dT + Q_p,\ \mathrm{kJ\ kg^{-1}} \tag{3}$$