Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Microwave induced plasma for solid fuels and waste processing: A review on affecting factors and performance criteria

Guan Sem Ho [a], Hasan Mohd Faizal [a,b], Farid Nasir Ani [a,*]

[a] Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310, UTM Johor Bahru, Johor, Malaysia
[b] Automotive Development Centre (ADC), Institute for Vehicle System and Engineering (IVeSE), Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310, UTM Johor Bahru, Johor, Malaysia

ARTICLE INFO

Article history:
Received 10 April 2017
Revised 4 July 2017
Accepted 8 August 2017
Available online xxxx

Keywords:
Microwave plasma
Gasification
Solid fuels
Solid waste
Hydrogen
Syngas

ABSTRACT

High temperature thermal plasma has a major drawback which consumes high energy. Therefore, non-thermal plasma which uses comparatively lower energy, for instance, microwave plasma is more attractive to be applied in gasification process. Microwave-induced plasma gasification also carries the advantages in terms of simplicity, compactness, lightweight, uniform heating and the ability to operate under atmospheric pressure that gains attention from researchers. The present paper synthesizes the current knowledge available for microwave plasma gasification on solid fuels and waste, specifically on affecting parameters and their performance. The review starts with a brief outline on microwave plasma setup in general, and followed by the effect of various operating parameters on resulting output. Operating parameters including fuel characteristics, fuel injection position, microwave power, addition of steam, oxygen/fuel ratio and plasma working gas flow rate are discussed along with several performance criteria such as resulting syngas composition, efficiency, carbon conversion, and hydrogen production rate. Based on the present review, fuel retention time is found to be the key parameter that influences the gasification performance. Therefore, emphasis on retention time is necessary in order to improve the performance of microwave plasma gasification of solid fuels and wastes.

Contents

1. Introduction . . . 00
2. Brief on microwave-induced plasma setup . . . 00
3. Factors that affects microwave-induced plasma gasification on solid fuels . . . 00
   3.1. Effect of O_2/fuel ratio and working gas flow rate . . . 00
   3.2. Effect of fuel characteristics . . . 00
   3.3. Effect of fuel injection method and location . . . 00
   3.4. Effect of microwave power . . . 00
   3.5. Effect of steam addition . . . 00
4. Conclusions . . . 00
   Acknowledgement . . . 00
   References . . . 00

1. Introduction

Currently, abundant amount of fossil fuels are widely consumed in power generation industry, thus causes a serious climate change due to the significant greenhouse gases emission (Yoon and Goo Lee, 2011). With an increase in awareness on climate change, waste-to-energy concept is gaining interest among researchers.

* Corresponding author.
E-mail addresses: guansemho@gmail.com (G.S. Ho), mfaizal@mail.fkm.utm.my (H.M. Faizal), farid@mail.fkm.utm.my (F.N. Ani).

http://dx.doi.org/10.1016/j.wasman.2017.08.015
0956-053X/

Please cite this article in press as: Ho, G.S., et al. Microwave induced plasma for solid fuels and waste processing: A review on affecting factors and performance criteria. Waste Management (2017), http://dx.doi.org/10.1016/j.wasman.2017.08.015

In the field of solid waste management, this concept needs an efficient technology in order to utilize the energy that contained in solid biomass and waste (Hlina et al., 2014; Leckner, 2015; Mountouris et al., 2006). Conversion of solid waste to energy is considered as a safe and cost effective sustainable technique to maximize the energy recovery and reduce the negative impact on our environment (Brunner and Rechberger, 2015; Khongkrapan et al., 2013; Lombardi et al., 2015).

The advancement of clean technology, for instance, plasma gasification is claimed to be a potential alternative technique for solid fuel and waste utilization, that is able to generate power and produce usable by-products as well as clean fuels (Khongkrapan et al., 2013; Messerle et al., 2016; Mountouris et al., 2006; Yoon and Goo Lee, 2011). Therefore, the plasma gasification stands out as an attractive method among various gasification technologies (Danthurebandara et al., 2015).

In general, gasification process converts solid waste into fuel which is dominated by synthesis gas (syngas). In details, the process involved the breakdown of the organic element and conversion of the inorganic element into reusable or safely disposable residue (Ismail and Ani, 2015). Conventional gasification operates at relatively low temperature (400–850 °C) that is maintained by partial oxidation of the fuels without any external heat supply. However, the conventional method has disadvantages in terms of costly air separation unit and much longer time to heat up. In addition, the products of the conventional method are dirtier compared to plasma gasification because of chars, tars and soot formation. But those limitations can be eliminated by using plasma for gasification process.

Plasma which is a fourth state of matter claimed by Fridman, is formed by ionization of gaseous matter (Fridman, 2008). The application of plasma in gasification reactions was claimed to have similar reaction mechanism to that of conventional gasification (Kalamaras and Efstathiou, 2013; Yoon and Goo Lee, 2011). In addition, plasma treatment were capable to produce stream gas with high hydrogen content from different types of hydrocarbon feedstock and the conversion efficiencies became nearly 100%. This is mainly contributed by the plasma characteristics which are able to promote the favourable chemical reactions even without catalyst. Those highly active species contain in the plasma such as ions, radicals and electrons are actually thousands of degrees higher than the surrounding temperature, thus promotes the effective rate of chemical reaction and their role is similar to that of catalyst (Henriques et al., 2011; Hrycak et al., 2014; Watanabe and Tsuru, 2008; Yoon and Lee, 2012). Due to the capability of gasification even under anaerobic condition (Mountouris et al., 2006, 2008; Yoon and Goo Lee, 2011), a stoichiometric amount of oxygen, air, carbon dioxide or other appropriate component is added to avoid the carbon formation in the gasification products (Hlina et al., 2014). With such high temperature, plasma gasification was able to breakdown tars, char, and dioxins (Mountouris et al., 2006, 2008). Therefore, the plasma gasification technology is recognised as closest to "true gasification" (Mountouris et al., 2008; Yoon and Goo Lee, 2011).

Despite of numerous advantages of the plasma gasification, this type of gasification is known as a high energy consumption method (Hlina et al., 2014), and this becomes a major drawback especially for high temperature thermal plasma. Therefore, non-thermal plasma, for instance, microwave plasma with comparatively lower temperature is getting attentions from researchers due to the advantage of lower energy consumption (Sanlisoy and Carpinlioglu, 2017). Besides, microwave induced-plasma also has the advantage of lower setup cost due to the ability of operation under atmospheric condition and comparatively more compact in size. Problems like products contamination caused by the electrode erosion and extra cost for electrode replacement can be eliminated because the microwave plasma setup is electrodeless. Microwave-induced plasma was found to be practical for reforming, decomposition, gasification, pyrolysis, purification, sterilization and surface modification (Jasiński et al., 2013). According to the review on hydrogen production technologies, plasma reforming processes for hydrogen production was claimed to be able to give efficiencies that falls within the range of 9–85% (Kalamaras and Efstathiou, 2013). The broad range of efficiencies indicates that there are still more rooms for optimizations by using different fuels, produced by various setup and operating conditions.

Previously, a review that focused on gas heating values and volume percentage of gas produced by different plasma treatment has been performed by Ismail and Ani (Ismail and Ani, 2015). Then, in the following year, Sanlisoy has provided a brief review on the plasma gasification application for solid waste disposal (Sanlisoy and Carpinlioglu, 2017). The aforementioned study focused on outlines of recent works related to plasma gasification systems, mainly emphasized on solid waste (Sanlisoy and Carpinlioglu, 2017). However, the aim of this review article is to provide an overall feature on how specific operating conditions affect the output, specifically on microwave–induced plasma gasification of solid fuels. The outline is started with a brief explanation on microwave-induced plasma setup and followed by factors that affect the outputs of microwave plasma treatment.

In addition, the present review also covers both operating conditions, with and without oxygen. Microwave-induced plasma gasification is still in development stage, in which to be a long term implementation maturity technology (Kalamaras and Efstathiou, 2013; Mizeraczyk and Jasiński, 2016). Therefore, the available parameters that have been investigated by previous researches are enclosed. In addition, further explanation on several performance criteria such as efficiency, carbon conversion, and hydrogen production rate are included.

2. Brief on microwave-induced plasma setup

Based on literature review conducted, most of the microwave-induced plasma application studies used 2.45 GHz microwave magnetron with highest microwave power of 6 kW and Fig. 1 below shows the general illustration of microwave plasma system setup (Ann et al., 2014; Bundaleska et al., 2013; Choi et al., 2016; Henriques et al., 2011; Hong et al., 2015, 2012; Hrycak et al., 2012; Jasiński et al., 2013, 2008a; Khongkrapan et al., 2014,

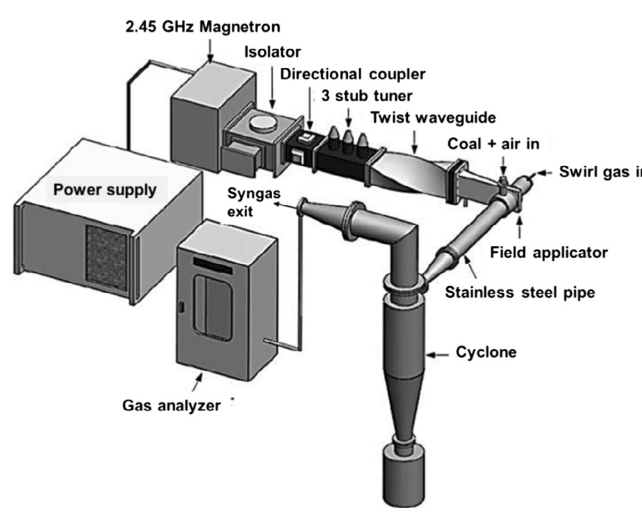

Fig. 1. Schematic drawing of the experimental microwave plasma gasification system (Hong et al., 2012).