INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–11

Available online at www.sciencedirect.com

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Gasification of non-recycled plastic packaging material containing aluminum: Hydrogen energy production and aluminum recovery

Cheng-Han Lu [a], *Kung-Yuh Chiang* [b,*]

[a] *Department of Environmental Engineering and Science, Feng-Chia University, Tai-Chung, 407, Taiwan, ROC*

[b] *Graduate Institute of Environmental Engineering, National Central University, Tao-Yuan, 320, Taiwan, ROC*

ARTICLE INFO

Article history:
Received 27 March 2017
Received in revised form
30 August 2017
Accepted 10 September 2017
Available online xxx

Keywords:
Gasification
Non-recycled plastic
Plastic packaging material
Syngas

ABSTRACT

This research aims to recover aluminum and hydrogen energy from non-recycled plastic material containing aluminum (NRP) using gasification. The gasification was conducted by a lab-scale fixed bed gasifier with controlling different temperature and equivalent ratio (ER) ranged from 600 °C to 900 °C and from 0.10 to 0.30, respectively. According to the syngas yield analytical results, the syngas yield increased significantly with an increase in ER. In the 900 °C case, the syngas yield increased from 4.47 m^3/kg to 7.73 m^3/kg with ER increasing from 0.1 to 0.3. This is because good gasification practice occurred at higher ER resulting in oxidation and exothermic reactions. Based on the measured syngas composition results, the H_2 and CO fractions increased with increased gasification temperature. In the ER 0.3 case, as the gasification temperature increased from 600 °C to 900 °C, the H_2 and CO fractions increased from 0.64 mol.% to 15.54 mol.% and from 2.89 mol.% to 15.54 mol.%, respectively. The syngas heating values were calculated ranging between 0.8 MJ/Nm^3 and 5.1 MJ/Nm^3. Meanwhile, cold gas efficiency (CGE) was approximately 72.2%, implying that 72.2% recovered energy was produced from gasified non-recycled plastic packaging material containing aluminum. The major recovered aluminum speciation was metallic aluminum using XRD identification. The recovered aluminum purity and recovery ranged from 73.1 wt% to 100.0 wt% and from 79% to 105%, respectively. In summary, the hydrogen energy production and aluminum recovery produced from non-recycled plastic packaging material containing aluminum using gasification was successfully developed.

Introduction

Resource recovery reached 48% at the end of 2016, assigned to the efforts of people and the government of Taiwan [1]. The number of publically announced recovery events is in the dozens, but municipal solid waste (MSW) resource recovery remains, especially for novel and laminar materials. One of the laminar materials is plastic packaging material, or so called "non-recycled plastic". According to MSW composition statistics in 2016, about 15% of plastic is found in MSW while the majority is non-recyclable plastic (10% in MSW). Hence about 350 kilo-tons of non-recycled plastic is sent to

* Corresponding author.
E-mail address: kychiang@ncu.edu.tw (K.-Y. Chiang).

https://doi.org/10.1016/j.ijhydene.2017.09.041

incineration every year with an annual MSW collection of 3.5 mega-tons [1].

The commonly non-recycled plastic in MSW is plastic packaging materials containing aluminum, except for normal plastic bags. The plastic packaging material containing aluminum is comprised of multi-layered plastic and metal. This material is difficult to reuse or reshape into secondary materials. However, the heating value of plastic packaging material containing aluminum could be higher than that of biomass due to the plastic packaging material was mainly composed of carbon and hydrogen [2,3]. This packaging material contains some metals that can be recovered in thermal recovery processing. There are advantages that could be accomplished by converting plastic packaging materials containing aluminum into energy and collecting the metal through residual material processes. Consequently, the waste treatment, energy application, metal recovery, and reduction of mass in final disposal could be achieved.

Gasification is a promising technology that might become one of the plastic packaging material containing aluminum treatment solutions. In recent years, gasification was well studied in the waste-to-syngas process with MSW [4,5], waste plastic and its derived fuel [2], synthetic polymers such as tyre and PET [6], waste PVC cable [7,8], waste printed circuit boards (WPCBs) [9], automobile shredded residue [3] and electronic waste [10]. Many of commercial gasification plants have capacity from kilowatts to several megawatts are listed in other studies [11]. It was noticed that gasification technology could be economically feasible. Brems et al. (2013) reviewed many researches and suggested that the temperature and equivalent ratio (ER) in waste plastics gasification could be controlled at 600–800 °C and 0.2–0.4, respectively [12]. Furthermore, higher gasification temperatures should be applied to high-carbon materials [11], such as coal and plastic. Therefore, the energy recovery could be maximized by parameter optimization in plastics gasification.

Nevertheless, the amount of metal detected in non-recycled plastic packaging material containing aluminum could reduce the amount of raw materials consumed by recovering the metals using an appropriate process. Presently many groups published and found that some thermochemical methods like pyrolysis, gasification and molten salts technology with oxygen-free operation could separate valuable metals or stabilize the heavy metals in waste treatment processes. Haydary et al. (2013) successfully separated the aluminum foil from pyrolytic char and recommended that the temperature should be lower than 750 °C to inhibit aluminum foil oxidation in thermal treatment of aseptic tetrapak [13]. Based on the previous literature results, significant metal recovery could be achieved using thermal treatment with a limited oxygen atmosphere. On the other hand, after the syngas production and usable metal recovery, the slag was generated to reduce the final waste volume (slag) and stabilize the heavy metals at the end of the MSW gasification-melting process. Eventually, the slag was evaluated for use as aggregate for building applications [3,5].

The catalytic capacity of valuable metals in the waste might be induced and enhanced for waste conversion under thermal processing. Salbidegoitia et al. (2015) found that the conversion of organic parts was improved in WRCB molten salt-steam gasification. The char yield was reduced by the addition of nickel powder at 550 °C from 48.8% to 22.6% [10]. Predicting the partial oxidation result on the recovered aluminum into their oxides in the thermal process, active acid sites were easily formed in the alumina structure, transforming the organics into combustible gases by reacting as the Lewis acid or Brønsted acid [14]. Catalysis would then occur in the gasification of non-recycled plastic packaging material containing aluminum and increase the energy efficiency.

As it is well known, syngas can be produced in waste plastics gasification and the valuable metal can be recovered in the thermal process with oxygen-limited conditions. This study therefore attempted to evaluate the increase in syngas and aluminum recovery energy efficiency in non-recycled plastic packaging material gasification containing aluminum by modifying the temperature and ER. The study objectives were: (1) to establish a thermochemical technology and operating parameters that could both recover the energy (syngas) and resource (aluminum); (2) to analyze the syngas composition and evaluate the gasification energy efficiency enhancement; (3) to characterize the recovered aluminum and evaluate the feasibility of aluminum recovery.

Material and methods

Feedstock

Non-recycled plastic packaging material containing aluminum was randomly sampled from a general waste collection system. Samples were sealed in plastic bags after natural drying for about one week followed by tap water washing. Five types of non-recycled plastic packaging material containing aluminum were separated based on appearance. In order to easily feed the tested NRP into updraft gasification system, the tested NRP was cut and shaped into a pillar form to derive the fuel in a 10 mm diameter and 15 mm length with a density between 1.1 and 1.4 g/cm^3. The prepared NRP was stored in sealing bags. The moisture, volatiles matter, fixed carbon, ultimate analysis and aluminum content were determined following the national standards of the Taiwan EPA (NIEA R203, R205, M301, and M402) [15]. The moisture and ash content of the NRPs were ND~1.37 wt% and 1.15–4.57 wt% (Table 1). The volatile matter was greater than 85% on average but it was 63.01% on NRP04. The lower heating values ranged between 6690 kcal/kg to 8910 kcal/kg. The highest aluminum content was found at 32% on NRP04. Thus, the NRP04 sample was selected as the gasification feedstock to evaluate the energy and metal recovery in this study. The remaining non-recycled plastic packaging materials containing aluminum were considered normal plastics wastes. A TG/DTA (HITACHI TG/DTA 7300) was used to measure the decomposition and melting temperature to understand the thermal characteristics of NRP04. According to the thermogravity and heat flow curve results in Fig. 1, the major decomposition temperature of the NRP04 ranged from 250 °C to 500 °C. Two melting points could be found on the heat flow diagram, 106.8 °C and 659.7 °C, respectively. Therefore, it was supposed that the plastic in NRP04 was low density polyethylene (105–115 °C). The melting point at 659.7 °C was confirmed as the melting temperature of metallic aluminum.