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Oxygen Gasification of Municipal Solid Waste in a Fixed-bed Gasifier ☆

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ABSTRACT

Four waste materials, paper, wood, textile and kitchen garbage, in municipal solid waste were gasified separately with oxygen in a fixed bed reactor. The yields of products char, tar and gas, the composition of gas components H_2, CO, CO_2 and CH_4, and the lower heating value (LHV) were examined at temperatures between 700 and 900 °C and equivalence ratio (ER) between 0.14 and 0.32. Characteristics of gas evolution during gasification were investigated. Results show that a higher temperature improves the formation of H_2 and CO while lowers the yield of CO_2 and CH_4. The LHV of syngas increases with temperature and varies in the range of 6–10 $MJ \cdot m^{-3}$, reaching the maximum at 800 °C or above. As ER increases, both combustible gas component and LHV of syngas decrease while the yield of CO_2 rises linearly. The appropriate ER for obtaining high quality gas is in the range of 0.18–0.23. Temperature and ER have significant effects on the product distribution. Higher temperature and ER are favorable for higher gas yield and lower yield of char and tar in the gasification of textile and kitchen garbage. At 800 °C, the gas evolution may be divided into two regions. In the first region, the flow rate of gas increases and then decreases rapidly, while in the second region the flow rate decreases monotonically to lower level.

1. Introduction

Because of land wastage and seepage of toxic decomposition products out of landfill areas, landfill disposal of municipal solid waste (MSW) is becoming environmentally less desirable [1–3]. Conventional incineration has problems of dioxins and final disposal of burnt ash, and its energy utilization efficiency is low [4,5]. Thus the gasification that converts MSW through partial oxidation into a fuel gas with appropriate heating value is becoming one of the best alternatives for the reuse of MSW. Especially, the process can reduce the emission of dioxins and heavy metals effectively, which is strongly concerned by the public when MSW is combusted [6]. Some researches on MSW gasification have been performed during the past decade. Xiao *et al.* reported air gasification characteristics of waste wood, paper and plastics using a fluidized bed gasifier [7]. Ahmed and Gupta investigated the characteristics of syngas from pyrolysis and gasification of waste food and rubber [8]. However, the gas produced from the air gasification is highly diluted by nitrogen, lowering the lower heating value (LHV). The use of oxygen has been proven effective for reducing the dilution effect and achieving a medium heating value. Yoon *et al.* compared the gasification results with air and oxygen separately for biodiesel by-product and found that the LHV of syngas and carbon conversion with oxygen was higher [9]. Therefore, MSW gasification with oxygen may be a promising technique to produce fuel gas of high quality.

So far, little work has been found using oxygen for gasification. In this study, four representative and important materials in MSW, paper, wood, textile and kitchen garbage, are chosen as experimental samples to investigate the characteristics of syngas produced from oxygen gasification in a fixed bed. The effects of temperature and equivalence ratio (ER) on the product distribution and syngas evolution in the gasification process are examined.

2. Experimental

2.1. Material

Four materials in MSW were involved in the experiments: paper, wood, textile and kitchen garbage, from waste typing paper, waste wood, waste cloth and waste family food, respectively. The materials were first dried under the sun for 2 days to reduce the moisture content and then shredded into particles in sizes of approximately 2 mm by a shredder. The analysis results are listed in Table 1.

2.2. Procedure

Gasification tests of MSW were carried out at atmospheric pressure in a lab-scale fixed bed reactor shown in Fig. 1. The gasification system consisted of an oxygen supply, a fixed bed reactor, a condensate collecting flask, a gas cleaning section, and a gas analyzer system. The reactor with 60 mm ID was made of Inconel and could be externally heated by an electrical ring furnace with total heating length of 1000 mm. A 60 mm OD stainless steel feeding tube containing testing sample was placed in the inlet of reactor before test. In each test the electrical heater was turned

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Table 1
Properties of materials in MSW (dry basis)

Material	Proximate analysis/%				Ultimate analysis/%				
	M	V	FC	A	C	H	N	O	S
Paper	4.51	79.54	11.16	9.30	41.11	3.38	0.07	46.09	0.05
Wood	9.72	82.05	15.68	2.27	48.81	5.41	0.05	43.40	0.06
Textile	0.82	87.78	11.17	1.05	43.37	6.18	1.45	47.03	0.92
Kitchen garbage	18.2	67.14	17.49	15.37	40.04	3.22	2.59	38.45	0.33

on and the furnace was heated at a rate 10 °C·min^{-1}. After reaching the desired final temperature, the feeding tube was pushed into the heating zone and an oxygen flow at an appropriate equivalence ratio was introduced as a gasifying agent. The operating conditions for all experiments were as shown in Table 2. The reaction proceeded for the next 25 min. Subsequently, the heating and oxygen supply were stopped and the reactor was allowed to cool. Syngas exited from the reactor and passed through the condenser and scrubber in sequence for cooling and purification. Two ways were used for gas sampling and analysis. For the influence of temperature and ER, all the gas produced were first collected by a gas sampling bag and then sent to an Emerson Gas Component Analyzer for component analysis and mass measurement. For the gasification evolution, the clean gas was tested online to detect the component change with time. The amount of condensed tar in the glass condenser and the char left inside the reactor were measured by taking the difference in mass before and after the test.

3. Results and Discussion

The main reactions involved in the gasification process are given below [10], in which the value of reaction heat refers to the temperature 298.15 K.

Devolatilization $\quad MSW \rightarrow Char(C) + Tar + Volatile$

Secondary cracking $\quad Tar \rightarrow Light\ and\ Heavy\ hydrocarbons + H_2 + CO + CO_2$

Boudouard $\quad C + CO_2 \rightarrow 2CO + 172\ kJ \cdot mol^{-1}$

Water–gas $\quad C + H_2O \leftrightarrow CO + H_2 + 131.4\ kJ \cdot mol^{-1}$

CO shift $\quad CO + H_2O \leftrightarrow CO_2 + H_2 - 41.3\ kJ \cdot mol^{-1}$

Methanation $\quad CO + 3H_2 \leftrightarrow CH_4 + H_2O - 206.3\ kJ \cdot mol^{-1}$

The LHV of syngas is calculated by LHV (MJ·m^{-3}) = (CO × 126.36 + H_2 × 107.98 + CH_4 × 358.18) / 1000, where CO, H_2, and CH_4 are their volume percentages.

3.1. Effect of temperature

Temperature is crucial for the MSW gasification process [11]. In the present work, gasification temperature is varied from 700 to 900 °C in 50 °C increments. The effect of temperature on gas composition is shown in Fig. 2. The yield of H_2 of kitchen garbage increases monotonically from 10 to 20% with temperature, while that of other three materials show the same increase of about 5% from 700 to 800 °C and the same decrease of about 5% from 800 to 900 °C. For the four samples, the yields of CO_2 and CH_4 decline as temperature increases, while the yield of CO increases greatly. In the experimental range, the yield of CO_2 decreases sharply from 40% to 20% while that of CO increases from 20% to 40% approximately. On one hand, higher temperature accelerates the rate of devolatilization and cracking reactions of tar, producing more H_2 and CO [12]. On the other hand, higher temperature is conducive to move the equilibrium of Boudouard and water–gas reactions to the right hand side, leading to a marked drop in CO_2 content [13]. Besides, CO shift reaction and methanation reaction are exothermic and thus less dominate at higher temperature, increasing the production of CO to a certain extent. The yield of CH_4 is practically the same (5%–9%) for different samples and the variation with temperature is not significant.

In Fig. 2, the main gas composition shows evident differences for different waste materials. The differences are large at high gasification temperatures but reduce dramatically as temperature decreases. The yield of H_2 in gasification of kitchen garbage is the highest, which could be attributed to its high moisture content. More steam is produced by evaporation and steam reforming reactions of carbon, carbon monoxide and methane are favored. Because of high content of volatiles and low fixed carbon content, the heat and its transfer in gasification of paper and textile are better and more light gases (mainly CO and CO_2) are produced by cracking reactions [14]. Due to high content of fixed carbon in wood material, wood gasification results in a relatively high yield of CO_2 [10].

The effect of temperature and material on LHV of the syngas is presented in Fig. 3. The content of H_2 and CO with high LHV is larger, so higher gasification temperature leads to higher LHV and improves the syngas quality effectively. In particular, with the continuous decrease of CH_4 yield, there is a slight drop in LHV for paper, wood and textile

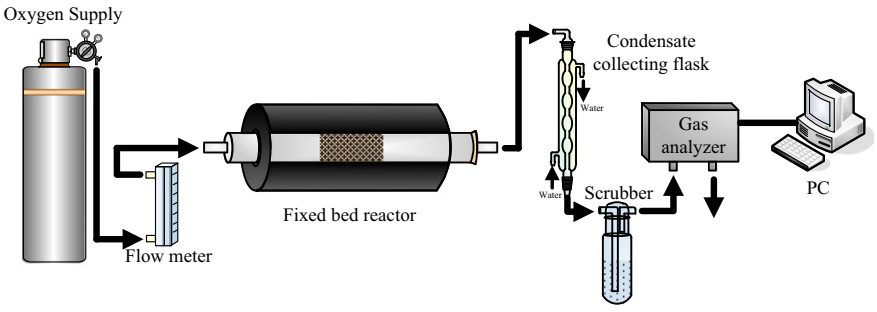

Fig. 1. Schematic illustration of the gasification apparatus.

Table 2
Summary of gasification operating conditions

Material	Sample amount/g	Particle size/mm	Oxygen flow rate/ml·min^{-1}	Gasification temperature/°C	Equivalence ratio
Paper	18.4	1-2	80-140	700-900	0.18-0.32
Wood	15.0	2-3	75-143	700-900	0.15-0.29
Textile	15.0	0.2-2	70-140	700-900	0.14-0.28
Kitchen garbage	20.0	0.8-1.5	78-121	700-900	0.18-0.28