

Production of synthesis gas by two-stage gasification of RPF in a lab-scale reactor

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ABSTRACT: Because of environmental effects and high oil prices, waster material is considered as an important energy source. In this paper, we introduce a two-stage process of gasification of RPF (Refuse Plastic Fuel) to generate synthesis gas in a lab-scale reactor. The process consisted of a pyrolysis part and a reforming part. First, the gas was produced through pyrolysis of RPF at 600 °C. Then, synthesis gas was produced through chemical reaction of collected pyrolysis gas with O₂ and steam in a reformer at 800 °C~1000 °C. Experimental conditions were determined by chemical equilibrium calculations. Experiment results shows that concentrations of CO and H₂ increased but THC concentration decreased as temperature is increased potentially due to the cracking of THC into CO and H₂ at such high temperatures. When steam and O₂ were injected, both of CO and H₂ yields were increased. Production of H₂ was also dependent on the amount of steam injection.

Keywords: gasification, pyrolysis, RPF, synthesis gas

1. INTRODUCTION

Due to the growth in population and industrial developments, demand of energy is rapidly increasing. Most of the energy currently consumed comes from fossil fuels. Fossil fuels cause many environmental problems such as global warming, destruction of an ecosystem and production of pollutants such as SO_x, NO_x, and dioxin which are harmful to human beings. As there is only a limited supply of fossil fuel, it is obvious that renewable and clean energy source is required [1].

Because of the lack of landfill sites, many countries restrict landfilling of combustible wastes. Consequently energy recovery from municipal solid wastes has recently received increasing attention [2].

Pyrolysis or gasification produces products that may serve as alternative sources of energy and chemical raw materials such as synthesis gas and char. Recently, many studies have addressed this issue in the laboratory and at the pilot plants. Chen experimentally investigated the partial oxidation of two different high-volatile pulverized coals in a tube furnace [3]. Song et al. investigated the co-gasification of coal and natural gas using a laboratory scale fixed bed reactor [4]. Yuehong et al.

compared the lab-scale experimental measurement on the co-gasification process with ASPEN Plus simulator [5]. Kajitani et al. gasified two types of coal chars with carbon dioxide or steam using a Pressurized Drop Tube Furnace (PDTF) [6]. Dou et al. investigated the kinetics for modelling pyrolysis through a thermo-gravimetry analysis under isothermal conditions between 300 and 600°C [7]. Kang et al. investigated reforming conditions of pyrolysis gas of RPF using STANJAN [8]. Dominguez et al. studied the feasibility of performing the drying, pyrolysis, and gasification of wet sewage sludge in a single process at high temperature [9]. Prahars et al. examined the kinetics of iso-octane steam reforming as a function of iso-octane and steam partial pressure at various temperatures [10].

This paper provides cracking or reforming characteristics of pyrolysis gases of RPF (Refuse Plastic Fuel) at various operating conditions in a small scale gasifying reactor.

2. Experiment

2.1 Materials

Samples of RPF were prepared to obtain the pyrolysis gas. An approximate analysis was carried out using the method described by American Society for Testing and Materials (ASTM) D5142. A more rigorous analysis was conducted using an elementary analyzer (EA1110, CE instrument). The caloric value of the sample (LHV) was obtained by the Dulong's equation

$$\text{LHV} = \text{HHV} - 900(\text{H} + \text{W})$$

where

$$\text{HHV} = 8100\text{C} + 34000(\text{H} - \text{O}/8) + 2500\text{S}$$

The characteristic of RPF samples are summarized in Table I.

2.2 Experimental set up

Figure 1 shows a schematic diagram of the experimental apparatus. It consists of

Table I: Characteristics of RPF

Proximate analysis	RPF(wt, %)
Moisture	0.04
Volatile matter	73.34
Fixed carbon	7.32
Ash	19.30
Ultimate analysis	RPF(wt, %)
C	63.10
H	8.59
O	11.45
N	0.19
S	0
Calorific value	RPF(kcal/kg)
LHV	6403.86

pyrolyzer and reformer (gasifier). In the previous study, Dou et al. investigated the kinetics of pyrolysis of refuse plastic fuel (RPF) through TGA (thermo-gravimetric analyzer) [7]. This study used gases from the pyrolyzer for the feed gas. The composition of the gas, which was measured by gas chromatography, is shown in Table II. The reformer with 50 mm diameter and 450 mm long is made of a dense alumina ceramic tube. We used a tubular electric furnace to heat and maintain the required temperature for reformer.

2.3 Experimental procedure

The pyrolysis gas, which was produced at the isothermal condition in the pyrolyzer, was carried to the gasifier for the reforming experiments. The flow rate of pyrolysis gas is 3 L min⁻¹ at the inlet of the gasifier. At higher temperatures (1100K-1400K), the concentrations of synthesis gas with injection of oxygen and steam were measured.

To find a suitable experimental condition, chemical equilibrium calculation is essential. Based on the simplified species and the thermodynamic properties of those species, the amount of synthesis gas is estimated through STANJAN, chemical equilibrium solver, in the range of O₂/O_{2,stoi} 10-50%.

Kang et al. investigated these operating conditions in their previous study [8]. Figure 2 shows effects of oxygen ratio by chemical equilibrium calculation. Figure 2 presents the profile of the mole fraction with the ratio of $O_2/O_{2,stoi}$.

We set experimental conditions using the results from this chemical equilibrium calculation. Table III shows experimental conditions.

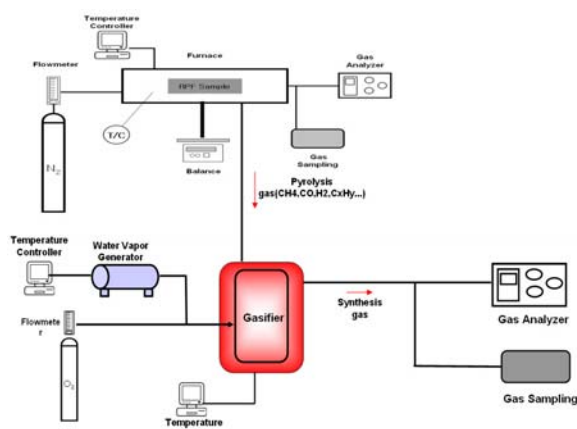


Figure 1: a schematic diagram of the experimental apparatus

Table II: Concentrations of pyrolysis gas compounds

Species	Molecular formula	Mole fraction (%)
Ethylene	C_2H_4	26.817
Methane	CH_4	22.108
Carbon monoxide	CO	9.346
Carbon dioxide	CO_2	8.447
Hydrogen	H_2	6.732
N-Butane	C_4H_{10}	5.355
Ethane	C_2H_6	5.327
1,3-Butadiene	C_4H_6	3.528
Benzene	C_6H_6	3.457
1,3-Pentadiene	C_5H_8	2.952
N-Pentane	C_5H_{12}	2.108
1-Pentene	C_5H_{10}	1.195
Propane	C_3H_8	0.914
1-Hexene	C_6H_{12}	0.309
Cyclopropene	C_3H_4	0.169
Ethylbenzene	C_8H_{10}	0.141
Other		1.096
Total		100

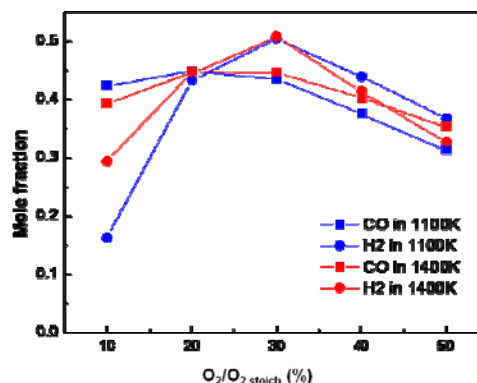


Figure 2 Mole fractions of CO and H₂ for various $O_2/O_{2,stoi}$

Table III Parameters of experiments

Parameters	Range
$O_2/O_{2,stoi}$	10, 20, 30, 40
Steam/fuel	0, 40, 80
Temp(K)	1100, 1200, 1300, 1400

3. Result and discussion

3.1 Effects of O_2 ratio

Figure 3 and Figure 4 show the effects of oxygen. At 1300K, concentration of H₂ is maximized at 20% of $O_2/O_{2,stoi}$ ratio and CO is maximized at 30% of $O_2/O_{2,stoi}$ ratio. These results are similar to the results of the chemical equilibrium calculation.

3.2 Effects of Steam injection

Figure 5 and Figure 6 show the effects of steam injection at 20% of $O_2/O_{2,stoi}$ ratio. We could produce more amounts of H₂ and CO at 40 of steam/fuel ratio than no steam injection condition. Theoretically the more steam is injected; the higher H₂ yield is expected. However, at 80 of steam/fuel ratio, the amount of H₂ produced decrease. To resolve this discrepancy, the further investigation is required.

In Figure 7, experimental results for 20% of $O_2/O_{2,stoi}$ ratio and temperature of 1300K are compared. Concentrations of each species (H₂, CO, THC) are presented for 1)

pyrolysis gas, 2) synthesis gas without steam injection, and 3) synthesis gas with steam injection. As seen in this figure, the amounts of both H_2 and CO are increased and that of THC (Total Hydrocarbon) is decreased when pyrolysis gas of RPF is gasified in a lab-scale reactor.

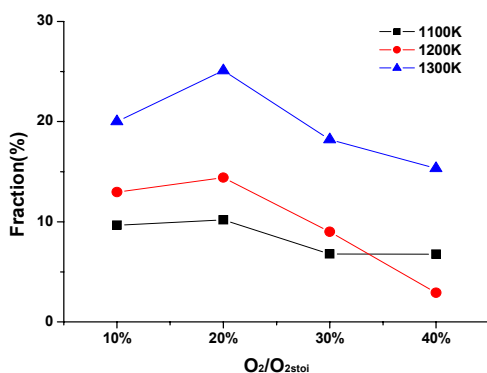


Figure 3 Mole fractions of H_2 for various $O_2/O_{2,stoi}$

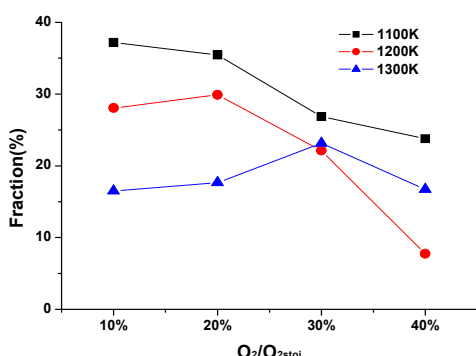


Figure 4 Mole fractions of H_2 for various $O_2/O_{2,stoi}$

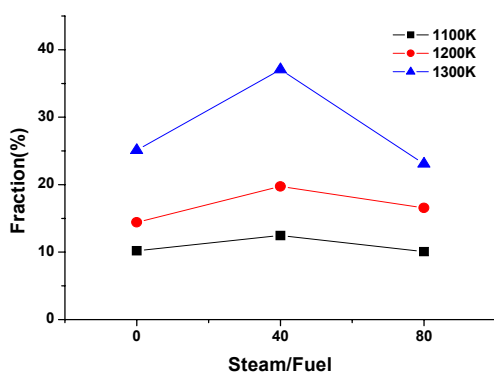


Figure 5 Mole fractions of H_2 for various Steam/fuel ratio

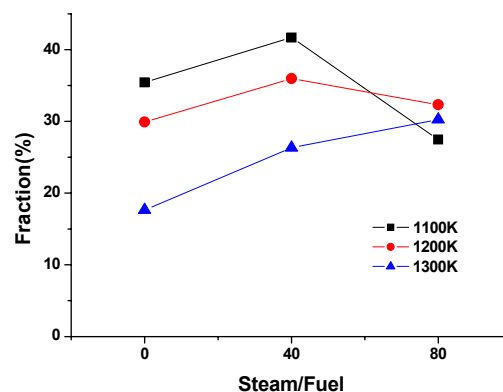


Figure 6 Mole fractions of CO for various Steam/fuel ratio

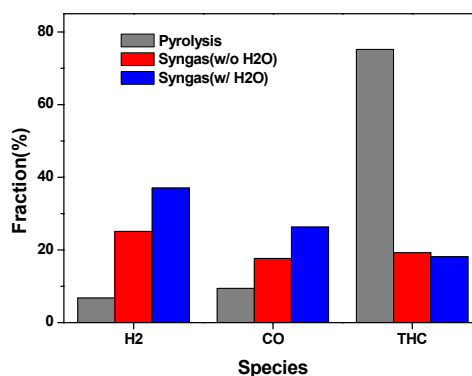


Figure 7 Mole fractions of H_2 , CO and THC (20% O_2 , 1300K)

4. CONCLUSIONS

This study has examined the characteristics of a lab-scale reactor for the gasification and its optimal operating conditions through gasification of pyrolysis gas of RPF. In summary,

1) As pyrolyzed gas of RPF went through reactor, THC was decreased while CO and H_2 were increased. Additional gasification of THC into CO and H_2 could be expected in the gasifier.

2) As steam was injected, the yield of both H₂ and CO increases compared with gasification without steam injection.

3) Chemical equilibrium calculation could predict the result of the experiment qualitatively.

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