

## 기포 유동층 내에서 RDF 화의 연소 특성

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### Characteristics of RDF Char Combustion in a Bubbling Fluidized Bed

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도시 폐기물 연료(RDF) 가스화 공정에서 생성되는 화를 보조 연료로 사용할 수 있는지 가능성을 알아보기 위하여 연소실험을 수행하였다. RDF 화의 고위 발열량은 3000~4000 kcal/kg이었고 염소 함량은 염소기준치함량보다 낮았다. 이는 보조 연료로서의 가능성을 보여주는 것이다. 연소 배가스에서, 최대 NO<sub>x</sub>와 SO<sub>2</sub>의 농도는 각각 240 ppm과 223 ppm이었다. 만약 후처리 공정이 적용되면, 이들의 농도를 대기 오염배출기준을 충분히 만족시킬 수 있게 낮게 제어 가능할 것이다. HCl의 농도는 상대적으로 높았으며, 이는 RDF 연소시 HCl 배출에 주의를 기울여야 함을 의미한다. 반응기 내의 온도 분포, O<sub>2</sub>와 CO<sub>2</sub>의 농도변화, 고체 잔사물의 양과 연소 손실로 미루어 볼 때, 과잉공기비가 1.3이 사용되었을 때 연소 반응이 가장 안정적이었다.

The feasibility of applications of the char obtained from a gasification process of municipal-waste refuse derived fuel (RDF) as an auxiliary fuel was evaluated by combustion experiments. The higher heating value of the RDF char was 3000~4000 kcal/kg and its chlorine content was below the standard requirement demonstrating its potential as an auxiliary fuel. In the combustion exhaust gas, the maximum NO<sub>x</sub> and SO<sub>2</sub> concentrations were 240 ppm and 223 ppm, respectively. If an after-treatment is applied, it is possible to control their concentrations low enough to meet the air pollutant emission standard. The HCl concentration was relatively high indicating that a care should be taken for HCl emission from the combustion of RDF. Based on the temperature distribution within the reactor, the concentration change of O<sub>2</sub> and CO<sub>2</sub>, and the amount and the loss on ignition of solid residue, it was inferred that the combustion reaction was the most reliable when the excess air ratio of 1.3 was used.

**Keywords:** refuse derived fuel (RDF), char, auxiliary fuel, combustion characteristics

### 1. Introduction

In response to global warming, efforts are being made worldwide to develop alternative clean energies that can replace conventional fossil fuels and emit less greenhouse gases and air pollutants. A number of countries over the world are trying to secure technologies for renewable energies such as wind, photovoltaic, solar thermal, geothermal, small-scale hydroelectric, wave and tidal energies that fit their circumstance the best[1]. In Korea, having small land area and limited natural resources, waste-to-energy is an efficient and realistic measure to sup-

ply renewable energy reliably with low cost.

Refuse derived fuel (RDF) is a fuel produced by shredding and dehydrating combustible and biodegradable municipal solid waste. Before it is compressed into pellets or other processed forms, glass and metals are removed. RDF, having a similar level of heating value to coal, is an example that represents the ongoing waste-to-energy policy of Korea. Several municipal-waste RDF plants are in operation in Korea with various scales, e.g., 80 ton/day in Wonju, 200 ton/day in Sudokwon landfill site, and 90 ton/day in Bucheon. Some other local governments are also pushing for construction of RDF plants indicating a large increase in RDF production in the near future. While RDFs produced in Korea are currently used in cement plants and for heating and air conditioning of buildings, RDF power plants will be the main consumer

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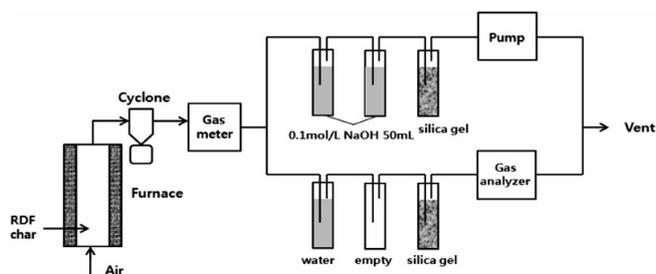


Figure 1. Schematic diagram of experimental apparatus.

of RDF in the future[2]. For efficient use of RDF, researches on combustion, pyrolysis and gasification of RDF are of great importance.

Gasification is a partial oxidation reaction in which carbon-containing materials are converted into combustible gaseous products. The by-products of gasification include the solid residue called char and tar and oil in liquid phase. Containing considerable amount of organic components, char has a potential as a fuel[3,4]. However, research on the characteristics of combustion and pollutant emission of char is very limited.

In this paper, a feasibility study for the use of char as an auxiliary fuel is reported. The combustion characteristics of RDF char and emissions of air pollutants are assessed experimentally.

## 2. Experimental

### 2.1. Sample preparation

The RDF pellets produced from an RDF plant in W city were used in this study. The char sample was produced through gasification reaction of RDF in a fixed gasification reactor at 600 °C for 2 h. Proximate and ultimate analyses and higher heating value (HHV) measurement were carried out to characterize the produced RDF char.

### 2.2. Method

RDF char was burned for 40 min with a feed rate of 1 kg/h at above 800 °C for spontaneous combustion. Experiments were carried out with three different excess air ratios of 1, 1.3, and 1.5. Temperature change in the furnace was measured continuously using a K-type thermocouple during the experiments. CO<sub>2</sub>, O<sub>2</sub>, NO<sub>x</sub>, and SO<sub>x</sub> contained in exhaust gas were analyzed by a portable gas analyzer (MK2, Greenline, Italy). CO was analyzed using gas chromatography (GC). HCl was measured using the mercury (II) thiocyanate absorption spectrophotometry prescribed in the Korean Standard Methods for the Examination of Air Pollution. After the reaction ended, the amount and the loss on ignition (LOI) of solid residue were measured to evaluate the combustion reaction. Figure 1 shows the schematic of the RDF char combustion system used in this study.

## 3. Results and Discussion

### 3.1. Preliminary Experiments

The results of proximate and ultimate analyses and HHV measurements

Table 1. Main Characteristics of RDF Char

Proximate analysis		Ultimate analysis	
Component	Content (wt%)	Component	Content (wt%) <sup>a</sup>
Moisture	0.1	C	44.3
Volatile matter	45.0	H	3.9
Fixed carbon	15.8	O	9.5
Ash	39.1	N	1.8
Higher heating value (kcal/kg)	4036.5	S	0.1
		Cl	1.3

<sup>a</sup> dry basis

for RDF char used in this study were summarized in Table 1. The considerable combustible amount (60.8%) and high HHV (4036.5 kcal/kg) demonstrates its potential as an auxiliary fuel. The contents of nitrogen, sulfur and chloride were shown to be 1.8, 0.1, and 1.3%, respectively, indicating that controls for NO<sub>x</sub>, SO<sub>2</sub>, and HCl contained in the exhaust might be required.

### 3.2. Change in Reactor Temperature under Different Excess Air Ratios

The char sample was introduced into the furnace after the furnace temperature reached at least 800 °C under three different excess air ratios of 1, 1.3, and 1.5. The change of the furnace temperature was then measured continuously for 40 min. The temperature in the furnace was shown to be stable when the excess air ratio was 1.3. When the excess air ratio was 1.5, temperature of the lower part of the furnace was lower than that measured under the excess air ratio of 1.3, which may be attributed to oversupply of unheated excess air.

### 3.3. Exhaust Composition under Different Excess Air Ratios

#### 3.3.1. CO Concentration

CO is an important factor for judging the degree of incomplete combustion[5]. CO concentration in the exhaust obtained under different excess air ratios did not vary much, being about 0.1 vol%. It is believed that relatively high concentration of CO was produced because no additional combustion with secondary air supply was applied in this study.

#### 3.3.2. Changes in O<sub>2</sub> and CO<sub>2</sub> Concentrations

O<sub>2</sub> is consumed by oxidation reaction and hence its concentration decreases as time elapses, while the concentration of CO<sub>2</sub>, which is a final product of oxidation, increases. The time evolutions of concentrations of O<sub>2</sub> and CO<sub>2</sub> measured under the excess air ratios of 1.3 and 1.5 are shown in Figure 2. Under the excess air ratio of 1.3, CO<sub>2</sub> concentration remained almost constant after 12 min from the beginning of the reaction. When the excess air ratio was 1.5, however, CO<sub>2</sub> concentration reached a maximum at 10 min from the beginning of the reaction and then decreased slowly. We inferred from this result that combustion took place more stably under the excess air ratio of 1.3.

#### 3.3.3. Change in NO<sub>x</sub> Concentration

NO<sub>x</sub> emission depends on the combustion temperature (thermal NO<sub>x</sub>)

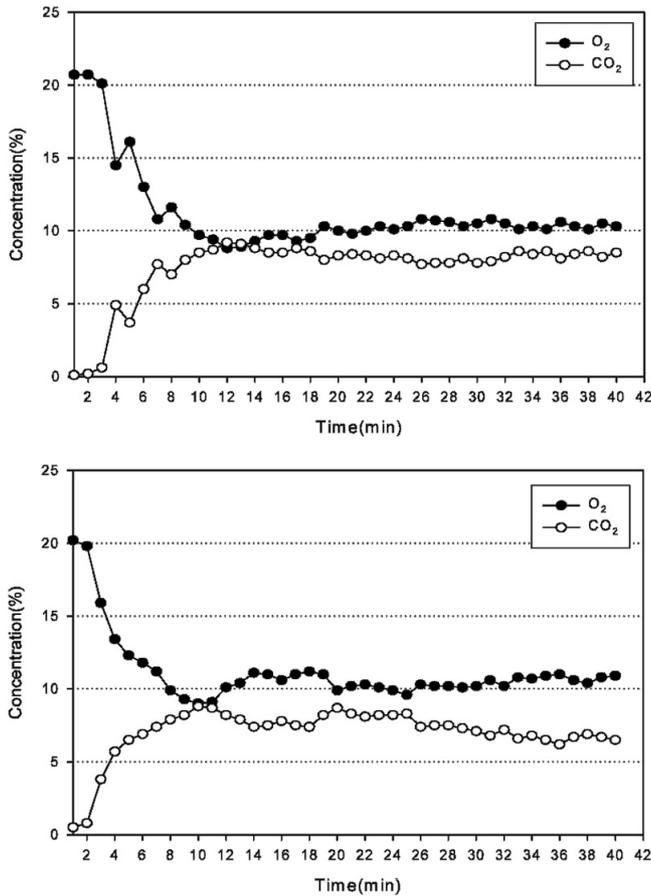


Figure 2. Concentration changes of O<sub>2</sub> and CO<sub>2</sub> (Air ratio, top : 1.3, bottom : 1.5).

and nitrogen content of the fuel (fuel NO<sub>x</sub>). In this study, all experiments were conducted at the same designated reaction temperature of 800 °C with the same fuel. Thus, the NO<sub>x</sub> concentration was expected to be dependent only on the excess air ratio that can alter the actual combustion temperature. Figure 3 shows the change in NO<sub>x</sub> concentration measured under two different excess air ratios. At the initial stage of the reaction, NO<sub>x</sub> concentration was higher under the higher excess air ratio, which can be attributed to more rapid temperature increase due to faster combustion aided by sufficient air supply. At 30 min from the beginning of the reaction, however, NO<sub>x</sub> concentration approached an asymptotic value that does not depend on the excess air ratio, which implies that the combustion reaction reached a stable status with the designated reaction temperature (800 °C). NO<sub>x</sub> concentration was below 240 ppm, which can be reduced to a lower concentration that meets the emissions standard by employing an after-treatment.

### 3.3.4. Change in SO<sub>2</sub> Concentration

The RDF sample used in this study was a low-sulfur fuel with the sulfur content of 0.1 wt%. The change in SO<sub>2</sub> concentration measured under two different excess air ratios is shown in Figure 3. Initially, the SO<sub>2</sub> concentration increased more rapidly under the higher excess air ratio because of promotion of combustion reaction by a larger amount

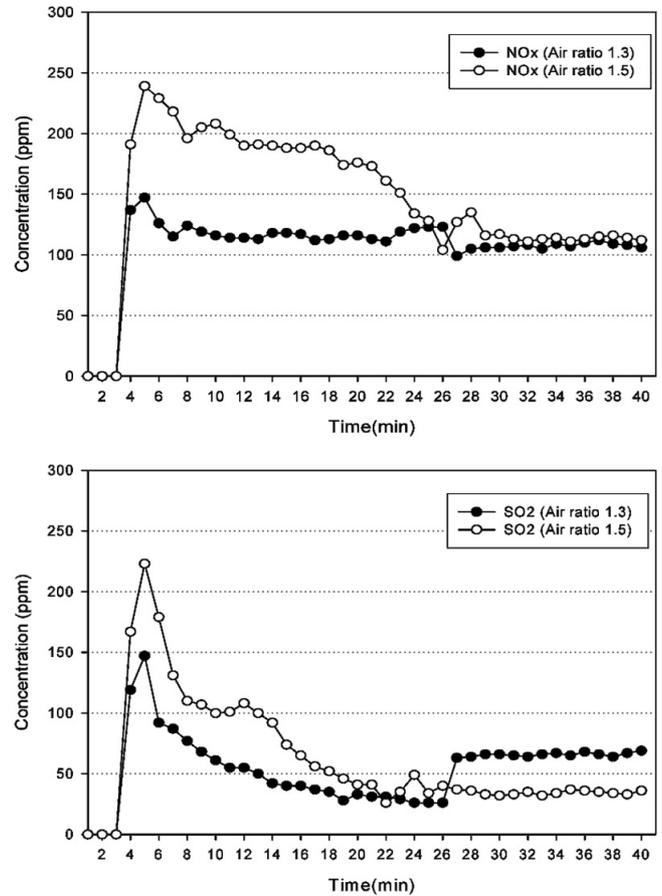


Figure 3. Concentration changes of NO<sub>x</sub> and SO<sub>2</sub> (top : NO<sub>x</sub>, bottom : SO<sub>2</sub>).

of air, which is consistent to the result for NO<sub>x</sub>. After 26 min from the beginning of the reaction, however, the SO<sub>2</sub> concentration was higher under the lower excess air ratio. In that the only mechanism of sulfur oxides production is oxidation of sulfur contained in the fuel, it is believed that higher SO<sub>2</sub> concentration indicates a more complete combustion[6]. The maximum SO<sub>2</sub> concentration measured was 223 ppm, which is low enough so that it is possible to meet the emissions standard if an after-treatment is employed.

### 3.3.5. Change in HCl Concentration

HCl is a precursor for production of dioxins : it reacts with oxygen during combustion reaction under the presence of particulate matter or metal catalysts to produce dioxins[7,8]. The Cl content of the fuel, which is an indicator of HCl emission, was 1.3 wt% that meets the Cl content standard for solid fuels (2.0%). The HCl concentration measured was dependent on the excess air ratio, with the maximum HCl concentration of 338 ppm, which should be taken into account for the combustion application of the char used in this study.

### 3.3.6. Combustion Residue and LOI

Because a small LOI value of the solid combustion residue indicates a large degree of complete combustion, a standard for LOI is usually included in the management standards for waste incineration facilities.

**Table 2. Solid Residual Products and Ignition Loss by Air Ratio**

Air ratio	1	1.3	1.5
Solid residual products (wt%)	45	39.6	42.5
Loss on ignition (wt%)	5.1	4.4	4.7

Under the current waste management law, the LOI standard is 5%. Because LOI correlates with emissions of unburned gas, fly ash, and bottom ash in waste combustion, the smaller LOI is, the less is the amount of secondary air pollutants emitted. To assess the degree of complete combustion in this study, the amount of combustion residue and its LOI were measured (Table 2) under three different excess air ratios. Both the amount of combustion residue and its LOI were the lowest under the excess air ratio of 1.3, indicating the most satisfactory combustion.

#### 4. Conclusions

Combustion characteristics of the char that was produced from gasification of RDF were investigated to evaluate the char as an auxiliary fuel. The HHV of RDF char was measured to be 3000~4000 kcal/kg, which is high enough to be used as an auxiliary fuel. The chlorine content was 1.3 wt%, less than the chlorine content standard of 2.0%. Based on the temperature distribution within the furnace, the excess air ratio of 1.3 resulted in the most stable temperature distribution. CO emission was high (about 0.1%) independent of the excess air ratio probably because there was no additional combustion with secondary air supply. O<sub>2</sub> and CO<sub>2</sub> emissions became constant at 12 min from the sample feed-in, being the most stable under the excess air ratio of 1.3. The concentrations of NO<sub>x</sub> and SO<sub>2</sub> in the exhaust gas were not higher

than 240 ppm and 223 ppm, respectively, which can be reduced below the air pollutant emission standard using after-treatment. HCl concentration in the exhaust gas was dependent on the excess air ratio, with the maximum of 338 ppm, which should be taken into account for the combustion application. The LOI of solid residue was lower than the standard under all excess air ratios tested in this study. The amount of solid residue and its LOI were the lowest when the excess air ratio was 1.3 indicating the most reliable combustion reaction.

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