

파일럿 규모 2단 가스화 시스템 공정을 이용한 RDF 가스화

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RDF Gasification Using a Pilot-Scale Two-Stage Gasification System

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본 연구에서는 W시에서 운영하는 RDF 생산시설의 펠렛 RDF를 이용하여 RDF의 가스화 반응으로 합성가스를 생산하였다. 생산된 RDF 촉를 소각로에 투입하여 연소과정에서 발생되는 열을 가스화로의 간접열원으로 이용하는 2단 가스화시스템 공정을 개발하였다. RDF의 가스화 반응 시간에 따른 합성가스 발생 비율과 잔재물(촉)의 빌열량 분석 등을 통하여 2단 가스화시스템 공정에서의 합성가스 생산 최적 운전조건을 연구하였다. 가스화로의 외부 열원 공급에 필요한 에너지 비용 저감을 위해 최적의 촉 체류시간을 도출하였다.

Syngas was produced out of pellet refuse derived fuel (RDF) produced from an RDF production facility of W city, Korea. A two-stage gasification system was developed to use the RDF char as an auxiliary heat source for gasification reaction. The composition and heating value of syngas as well as the heating value of residual product (char) were measured at a different residence time to investigate the optimal operating condition of the two-stage gasification system for syngas production. The optimal char residence time to minimize the energy cost due to an external heat source supply was also deduced.

Keywords: RDF, syngas, gasification, two-stage

1. Introduction

Global exhaustion of fossil fuels is leading to simultaneous increases in the prices of crude oil and coal. New and renewable energies are of growing importance in utilizing resources efficiently and controlling global warming. In particular, the gasification technology using wastes has drawn large attention because it can not only treat wastes but also provide syngas, a next-generation heat source with a high heating value, which can fuel gas engines and turbines of combined heat and power systems[1-10].

The samples that can be applied to gasification for energy recovery are combustible wastes including food waste, paper, wood, plastics, fabrics, rubber, leather, sewage sludge, and other combustible materials.

Waste energy accounted for about 76% of total new and renewable

energies of South Korea in 2007 indicating that waste-to-energy is the most promising measure for extending the use of new and renewable energies in this country.

The amount of available combustible waste is estimated to be about 4.41 million tons per year as of 2008, of which only about 1.3%, which accounts for about 60 thousand tons per year, is being used as energy source. In 2013, total available combustible waste is expected to be about 3.84 million tons per year, of which about 46%, accounting for 1.78 million tons per year, is supposed to be used as energy source[10].

Generally, there are two kinds of main applications of combustible municipal wastes as a renewable energy source: production of electricity and heat using waste heat from incinerators and production of solid fuels such as refuse derived fuel (RDF) through physical classification and treatment of wastes[2]. The waste-to-solid-fuel technology is in the level of verification in South Korea. In particular, poor market

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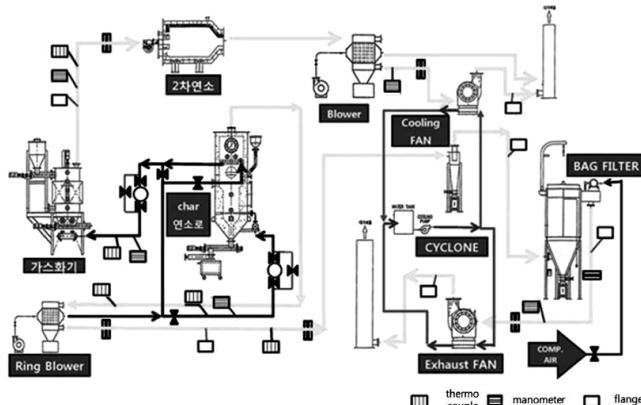


Figure 1. Configuration of RDF gasifier (20 kg/hr).

circumstances, including unstable demand and low supply price, and low operation efficiency are the main obstacles calling for researches for overcoming those problems. As the application of the combined heat and power technology using RDF is expected to increase rapidly, it is urgent to provide technical guides based on the characteristics of RDF-fueled power generation facilities to prevent market disorder and support technical management[10].

In this study, syngas and RDF char were generated through gasification using pellet RDFs produced from an RDF production facility of W city, Korea. A two-stage gasification process was developed, in which the produced RDF char was recycled to be used as a heat source for gasification reaction.

2. Experimental

2.1. Sample Preparation

Pellet RDFs produced from an RDF production facility of W city was used for experiments in this study. To minimize the influence of atmospheric moisture, the samples were stored in a container sealed tightly. Pellets with diameter and length of 1.5 cm and 6 cm, respectively, were selected for experiments. They were dried in a dryer for 48 h to remove moisture and were stored in a desiccator for 4 h before experiments.

2.2. Physicochemical Characterization of RDF

To characterize W-city RDF that is supposed to be used for the two-stage gasification system, proximate and ultimate analyses were conducted. Heating values of the samples were also measured.

The proximate analysis of RDF was conducted following the Korean Official Waste Test Method. The ultimate analysis was carried out using an elemental analyzer (Flash EA 1112 Series, CE Instruments/ThermoQuest Italia). Heating values of the RDF samples were measured using a calorimeter (IKA-C2000 basic).

2.3. Gasification System Setup and Thermo-gravimetric Analysis (TGA)

Figure 1 shows the schematic of the two-stage gasification system

Table 1. The Ultimate and Proximate Analysis of Target Pellet RDF

Proximate analysis (wt%)	Moisture	Ash	Combustibles	Heating value (kcal/kg)	
	1.3	18.1	80.6	4414.9	
Ultimate analysis (wt%)	N	C	H	O	S
	0.7	53.1	6.4	21.3	0.4

used in this study, consisting of a fixed-bed waste gasification reactor and a fluidized-bed incinerator for complete combustion of residuals. The system was designed with a capacity of 20 kg/h.

TGA analysis was conducted to investigate the pyrolysis/gasification characteristics of RDF samples. A thermo-gravimetric analyzer (Setaram TGA 92) was used to explore the thermal characteristics of RDF under temperature change in nitrogen and air atmosphere.

RDF samples were fed through a screw operating with a uniform rotation rate corresponding to the constant input feed rate of 20 kg/h. Air was warmed to about 50 °C by flowing through the incinerator before entering the gasification reactor. The residual char after gasification was fed into the incinerator by the second screw feeder installed at the lower part of the gasification reactor for complete combustion.

2.4. Gasification Reaction and Analysis

A two-stage gasification system and a batch type gasification reactor were used. To reduce the gasification reaction time, three different sizes of RDF samples were tested: 1.5 cm × 2 cm, 1.5 cm × 3 cm, and 1.5 cm × 6 cm (raw RDF). Initial gasification reactor temperature was 600 °C. Equivalence ratio (ER) was set at 0.1 for all experiments. The reactor was operated continuously with the feed rate and the residence time of RDF of 20 kg/h and 1 h, respectively.

The characteristics of syngas production from RDF gasification reaction were analyzed by using GC-FID/TCD with different RDF sample sizes and residence times. Residuals obtained with different residence times were proximate-analyzed following the Korean Official Waste Test Method. Ultimate analysis and heating value measurement were also carried out for the residuals.

3. Results and Discussion

3.1. Physicochemical and Pyrolysis Characteristics of RDF

Table 1 summarizes the results of ultimate analysis, proximate analysis, and heating value measurement of the RDF pallet.

The moisture and combustibles contents of RDF were measured to be 1.29% and 80.61%, respectively. The ash content was 18.1%, which is smaller than 20%, the standards of Korea and EU. Ultimate analysis showed that the carbon, nitrogen, and sulfur contents were 53.1%, 0.7%, and 0.4%, respectively. The oxygen content was calculated by $O = \{100 - (C + H + N + S + \text{ash})\}$. Heating value was measured to be about 4,414.9 kcal/kg. All the measurements were made in triplicate and the averages were taken.

Figure 2(a) and 2(b) show the TGA and the differential scanning calorimetry (DSC) analysis results, respectively, for W-city RDF. The

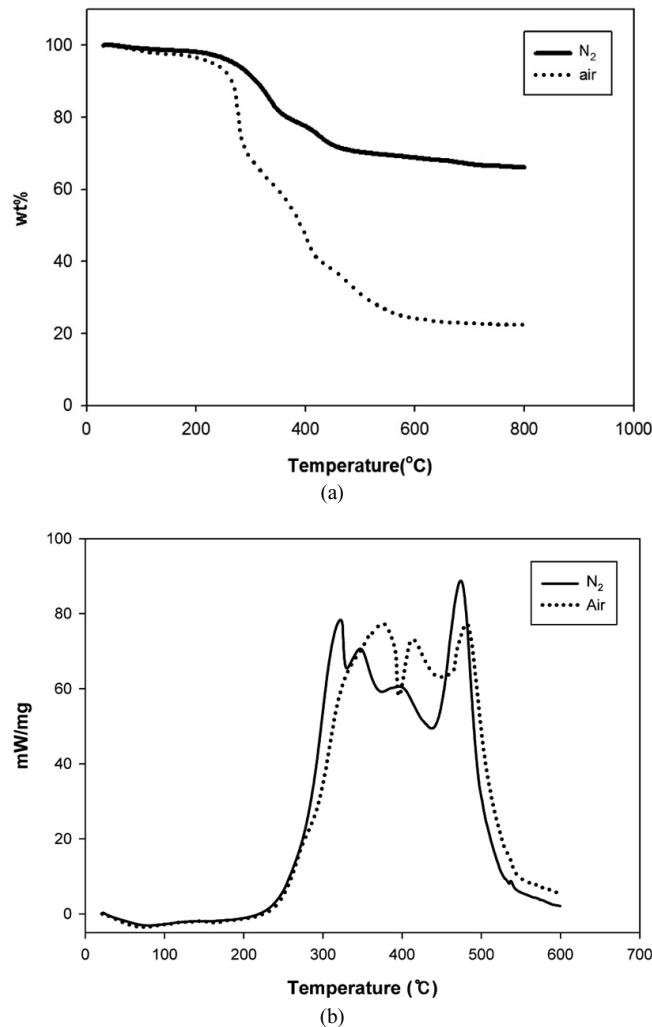


Figure 2. TGA (a) and DSC (b) curves of pellet RDF.

weight loss due to temperature rise was shown to be large under oxidizing atmosphere (air). Decomposition of RDF began at about 280 °C and the weight loss stopped at about 550 °C. Under reducing atmosphere (N_2), on the other hand, RDF decomposition started at about 250 °C and slow weight loss continued even above 800 °C. The total mass reductions were 75.2% and 32.6% under oxidizing and reducing atmospheres, respectively.

While TGA curves show the weight loss of samples due to temperature rise, DSC curves show the change in the amount of heat required to increase the sample temperature.

DSC analysis results showed that 3 components contained in RDF were decomposed under oxidizing atmosphere. Under reducing atmosphere, however, 4 components were shown to be decomposed. This result indicates that the decomposed components and the temperature at which the decomposition takes place may be different under oxidizing and reducing atmospheres.

3.2. Gasification Characteristics of RDF

Experiments were carried out to investigate the gasification characteristics of RDF by operating the gasification reactor with RDF

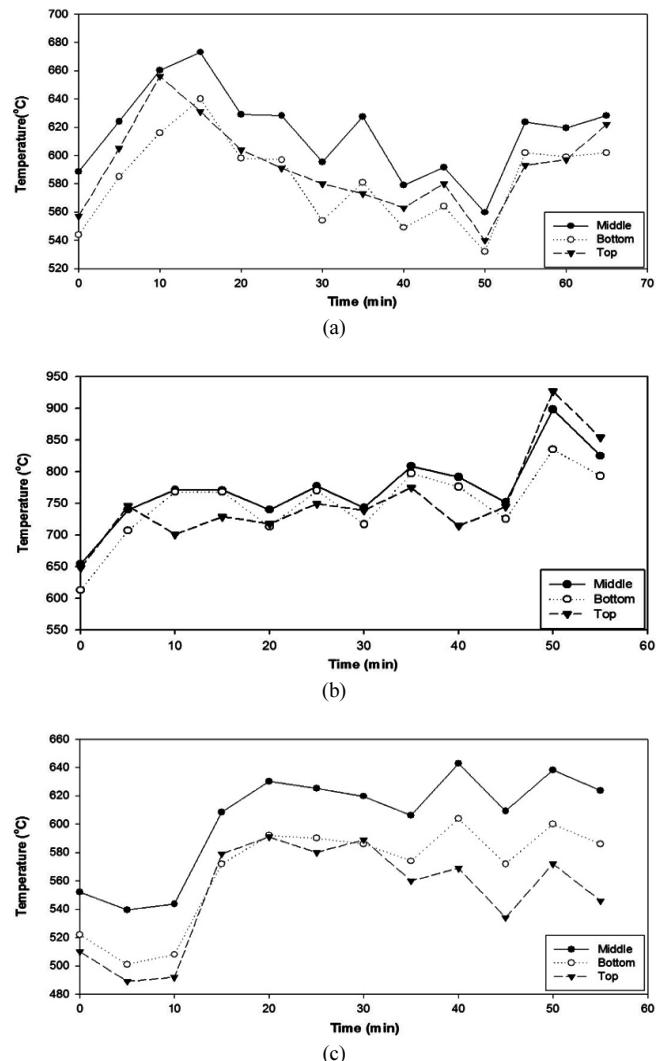
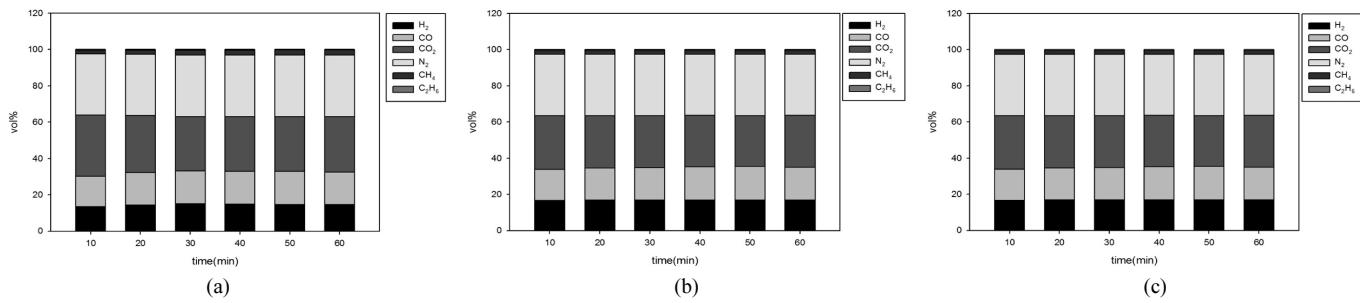


Figure 3. Effects of RDF size (1.5×6 cm) on the temperature change of RDF gasifier. (a) 1.5×6 cm, (b) 1.5×2 cm, and (c) 1.5×3 cm.

samples fed continuously by a screw. ER and initial reactor temperature were 0.1 and 600 °C, respectively. RDF samples were fed at a constant feed rate of 20 kg/h with three different sample sizes to investigate the effect of sample size on the gasification reaction. Gas-phase and solid-phase products were sampled every ten min. Temperature was measured at top, middle and bottom parts of the reactor every five minutes.

3.2.1. Temperature Change in the Reactor with Different RDF Sample Sizes

Figure 3 shows the temperature profiles measured during continuous operations with different RDF sample sizes. It is noticed that the reactor temperature reached as high as 900 °C for the smallest sample ($1.5 \text{ cm} \times 2 \text{ cm}$) with the smallest temperature variation within the reactor. This can be attributed to high reaction efficiency and corresponding high temperature increase due to large sample surface area.



* C_2H_2 , C_2H_4 : not detected

Figure 4. Characteristics of syngas in RDF gasification by size (a) 1.5×6 cm, (b) 1.5×2 cm, and (c) 1.5×3 cm.

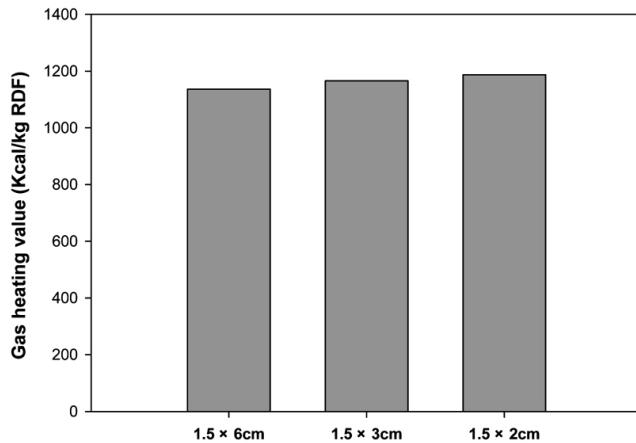


Figure 5. Effect of RDF size on heating value of syngas.

3.2.2. Syngas Production Characteristics with Different RDF Sample Sizes

Figure 4(a), 4(b) and 4(c) show the syngas compositions obtained with different sample sizes. Generally, the effect of sample size on the syngas composition was not very large. For raw RDF, H_2 and CO compositions were $13.4\sim14.6\%$ and $16.9\sim17.9\%$, respectively, while for the smallest sample ($1.5\text{ cm} \times 2\text{ cm}$), H_2 composition was almost constant (about 16.9%) and CO composition was $17.2\sim18.2\%$. The syngas composition for the $1.5\text{ cm} \times 3\text{ cm}$ sample was similar to that for the $1.5\text{ cm} \times 2\text{ cm}$ sample. H_2 and CO composition decreased with increasing RDF samples size, whereas CO_2 composition increased, with RDF sample size. It is presumed that with a smaller sample surface area (a larger sample size) the oxygen consumption rate per unit surface area is larger, which is preferable to production of CO_2 . In the case of raw RDF, it took about 20 min for the syngas to reach an asymptotic composition after the sample feeding, whereas it took about 10 min in the case of cut samples.

In summary, small RDF sample size seems to be preferable for syngas production.

3.2.3. Heating Value of Syngas

Figure 5 shows the heating value measurement results for the syngas produced from the two-stage gasification system. The heating values of the syngas produced from raw sample, the $1.5\text{ cm} \times 2\text{ cm}$ sample, and the $1.5\text{ cm} \times 3\text{ cm}$ sample were measured to be 1136.2, 1187.3 and

Table 2. Heating Values and Percentage of RDF Char with Residence Time

Continuous operation time*	Heat of Combustion (kcal/kg)	Incidence rates of residues(%)
10 min	2291.0	14.7
20 min	2855.0	
30 min	2321.5	
40 min	1824.0	
50 min	1548.7	
60 min	1378.6	

* Sample input 20 kg/hr

Table 3. The Ultimate Analysis of RDF Char by Residence Time Changes

Continuous operation condition*	N	C	H	O	S
10 min	0.5	27.8	0.6	5.2	0.2
20 min	0.7	28.0	1.8	2.5	0.2
30 min	0.5	22.6	1.2	1.9	0.2
40 min	0.3	19.2	0.4	3.2	0.2
50 min	0.4	19.8	0.4	1.3	0.2

* Sample input 20 kg/hr

1165.4 kcal/kg, respectively. The heating value was shown to decrease with increasing the sample size, which can be expected from the syngas composition discussed above.

3.3. Characteristics of Residual (char)

Char is generated as a residual product of gasification reaction. To evaluate the residual char as an auxiliary heat source for gasification reaction, char was sampled at different residence times and its characteristics were analyzed by ultimate analysis and heating value measurement.

Tables 2 and 3 show the heating value measurement results and the ultimate analysis results, respectively, for the residual char sampled at different residence times. The heating value of char increased with residence time initially, but decreased with increasing residence time later showing a maximum value at 20 min. The initial increase of heating value may be attributed to conversion of volatile components into fixed carbon under low oxygen condition. As the gasification

proceeds further, fixed carbon is converted into syngas resulting in the reduction of the char heating value due to increasing ash composition.

4. Conclusions

In this study, a two-stage gasification system was used to produce syngas out of RDF produced from an RDF production facility of "W" city, Korea. The feasibility of the use of the residual char as an auxiliary heat source for gasification reaction was assessed. The following conclusions were deduced from the experimental results.

1) TGA and DSC analyses of RDF showed that thermal weight loss is much larger under oxidizing atmosphere than under reducing atmosphere. Under reducing atmosphere (N_2), sample decomposition began at about 250 °C and slow reaction continued even above 800 °C. Total weight loss was 75.2 and 32.55% under oxidizing and reducing atmospheres, respectively.

2) The smallest (1.5 cm × 2 cm) RDF sample resulted in the fastest temperature rise and the highest reactor temperature, which is attributed to high reaction efficiency due to large sample surface area available for reaction. The syngas reached an asymptotic composition in 20 min after sample feeding in the case of raw RDF, whereas it took much shorter time (about 10 min) in the case of cut RDF samples. This result implies that a smaller RDF sample size will lead to production of a larger amount of syngas due to a higher reaction efficiency.

3) The heating value of syngas decreased with increasing sample size: 1,136.2, 1,187.3 and 1,165.4 kcal/kg for raw (1.5 cm × 6 cm) RDF, 1.5 cm × 2 cm sample, and 1.5 cm × 3 cm sample, respectively.

4) The heating value of residual char increased with residence time initially, but decreased with increasing residence time later having a maximum heating value at 20 min. The initial increase of heating value is probably due to conversion of volatile components into fixed carbon under low oxygen condition.

If the heating value of residual char is the only factor to be considered,

the optimal residence time for char is expected to be 20~30 min. It is possible, however, that the syngas yield will be too low with this char residence time. Therefore, the syngas yield and the energy cost have to be considered simultaneously to determine the optimal char residence time.

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