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Gasification characteristics of combustible wastes in a 5 ton/day fixed bed gasifier

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Abstract−The gasification characteristics of combustible wastes were determined in a 5 ton/day fixed bed gasifier (1.2 m I.D. and 2.8 m high). The fixed bed gasifier consisted of air compressor, oxygen tank, MFC, fixed bed gasifier, cyclone, heat exchanger, solid/gas separator, water fluidized bed reactor and blower. To capture soot or unburned carbon from the gasification reaction, solid/gas separator and water fluidized bed were used. The experiments with 10-50 hours of operation were carried out to determine the effects of bed temperature, solid/oxygen ratio and oxidant on the gas composition, calorific value and carbon conversion. The calorific values of the produced gas decreased with an increase of bed temperature because combustion reaction happened more actively. The gas composition of partial oxidation of woodchip is CO: 34.4%, H_2: 10.7%, CH_4: 6.0%, CO_2: 48.9% and that of RPF is CO: 33.9%, H_2: 26.1%, CH_4: 10.7%, CO_2: 29.2%. The average calorific values of produced gas were about 1,933 kcal/Nm^3, 2,863 kcal/Nm^3, respectively. The maximum calorific values were 3,100 kcal/Nm^3 at RPF/oxygen ratio: 7.

Key words: Combustible Waste, Gasification, Fixed Bed, Syngas

INTRODUCTION

The amount of waste generated domestically is about 0.25 million ton/day, and 0.17 million ton/day of waste generated has been recycled and the rest (0.07 million ton/day) has been incinerated or reclaimed in Korea [Kim et al., 2003]. The origin of combustible wastes is shown in Fig. 1. Combustible waste mostly consists of materials derived in polymer resin, plastic materials, biomass, and so on. Incineration might be used for reducing combustible wastes and heat recovery, but there are many environmental problems and limits of application. Therefore, gasification treatment of combustible wastes might be one of the options to replace incineration method. Also it would be applied for various fields after purification of produced gas [Heermann, 2000; Lee et al., 2001, 2004; Song et al., 2001].

Most of all, the applications of waste gasification technologies could be divided into the Lurgi process which was developed from the gasification process of medium carbon sources (highly C/H ratio hydrocarbon), such as coal, oil residue and so on, and Thermo-select process was developed from incineration [SVZ, 2000; Kim, 2003; Kim and Im, 2004]. The reactor type of these processes is mostly fixed beds which might not be affected by the characteristics of waste [Na et al., 2003]. The gasification reactions could occur free from production of pollutants such as SO_x, NO_x, dioxin and others. General applications of produced synthesis gas are power generation and raw material of chemical compounds such as methanol [Kurkela et al., 1993; Bridgwater, 1995; Dornburg and Faaij, 2001; Ko, 2001; Min et al., 2005]. However waste gasification processes have not been introduced into domestic industries because of excessive initial capital cost, the difficulty of choosing a suitable gasification process, low economic efficiency, and so on [Kim, 2003].

A pilot-scale gasification system was designed and produced and hot tests were performed to develop process technologies about the main reactor and other auxiliary processes and to introduce waste gasification processes into domestic industries. Also, the gasification characteristics of woodchip and RFP have been determined in the pilot plant. Especially, the effects of bed temperature, solid/oxygen ratio on the gas composition of produced gas, carbon conversion were analyzed.

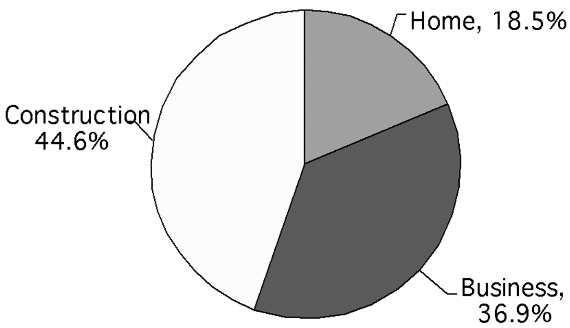

Fig. 1. Origin of combustible wastes in Korea.

EXPERIMENTAL

The gasification characteristics of waste woodchip and residue plastic fuel (RPF) were determined in a 5ton/day fixed bed gasifier (1.2 m I.D. and 2.8 m high); a flowchart and photograph of the gasification process are shown in Fig. 2. The fixed bed gasifier consisted of air compressor, oxygen tank, MFC, gasifier, cyclone, heat exchanger, solid/gas separator, water fluidized bed reactor and blower, and the details can be found elsewhere [Kim, 2003; Kim and Im, 2004]. Hot tests of the gasification process were performed over 10 hours, and woodchips and RPF from Korea were used for experiments. To increase bed temperature from room temperature to gasification temperature, an LPG burner, wood and cokes were used.

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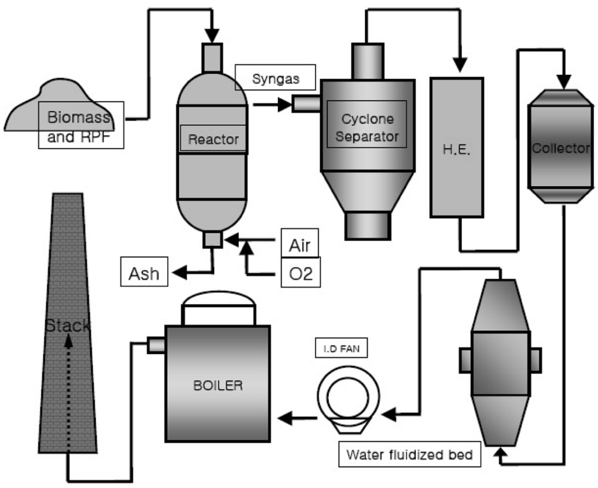


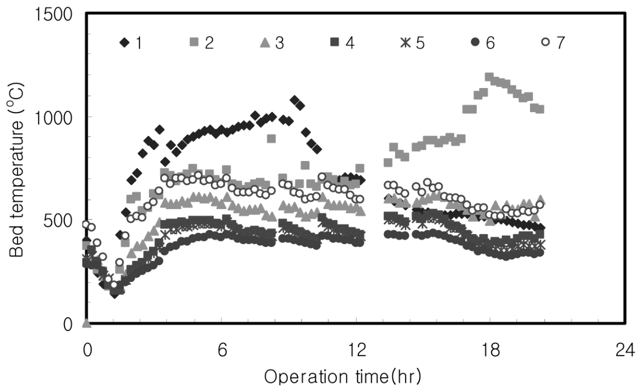
(a) Flow chart

(b) Photograph

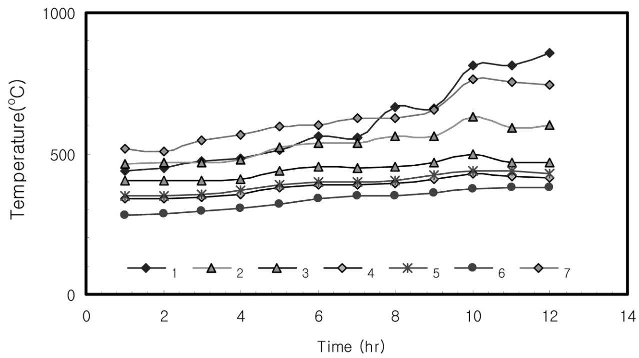
Fig. 2. Schematic diagram (a) and photograph (b) of 5 ton/day fixed bed gasifier.

Table 1. Approximate and elemental analysis of woodchip and RPF

		Woodchip	RPF
Calorific value (kcal/kg)		4,520	6,250
A. A.	Water	0.24	4.2
	C.M.	98.6	83.5
	Ash	1.24	12.3
E. A.	C	47.6	56.2
	H	6.16	7.67
	N	0.39	0.61
	S	0.01	0.00
	O	45.8	16.2



(a) Woodchip



(b) RPF

Fig. 3. Temperature profile in the gasifier (a) woodchip (b) RPF.

After the bed temperature arrived at gasification temperature, the bed temperature was controlled by controlling feeding rate or oxygen rate. To capture soot or unburned carbon from the gasification reaction, solid/gas separator and water fluidized bed were used. The experiments were carried out to determine the effects of bed temperature (500-1,000 °C), oxygen concentration (0-21 vol%) and solid/oxygen ratio (kg/h of woodchip and RPF/kg/h of oxygen, 0-15) on the gas composition, calorific value and cold gas efficiency of the produced gas.

Domestic combustible waste, of which 70% consisted of biomass such as pulp and wood, have been almost collected at the state of being not separated and so it has been reclaimed or incinerated. In opposition, the property of industrial waste is more uniform; therefore, it was selected as the object material in this study. The industrial waste consisted of 35% biomass and 65% synthetic resin. The approximate analysis and elemental analysis of woodchip and RPF are shown in Table 1 and their calorific value is 4,520 and 6,250 kcal/kg, respectively.

RESULTS AND DISCUSSION

The key point of 5 ton/day pilot plant design might be the basic design related with reactor and kinetics. Therefore, the reactor size was calculated by using experimental results of the lab-scale fixed bed gasifier [Na et al., 2003]. Also it was assumed that 4 step gas-solid reactions (Drying, Pyrolysis, Gasification and Combustion) would occur one after the other. As a result, the size of the 5 ton/day-scale gasifier might be over 2.8 m high and 1.2 m I.D. with woodchip and RPF (0.03 m×0.03 m×0.07 m).

In the gasification experiments of woodchip and RPF, the temperature profiles of the gasifier system are shown in Fig. 3. In that Fig. 7 is the inside temperature of gasifier (2.7 m high above the grid) and the others are the temperature of outside refractory (1 : 0.3 m, 2 : 0.7 m, 3 : 1.0 m, 4 : 1.5 m, 5 : 2.0 m, 6 : 2.5 m above the grid). As can be seen in Fig. 3, the bed temperatures of RPF were more stable than that of woodchip due to low water content and higher calorific value [Bridgwater, 1995; Dornburg and Faaij, 2001; Min et al., 2005]. However the bed temperature of woodchip is higher than that of RPF because of cokes to be used for heating materials. In the experiments of only using woodchip, the bed temperature of woodchip gasification was lower than that of RPF. At the other experiments the bed temperature of RPF gasification was over 1,000 °C due to higher calorific value and lower water content [Kim, 2003; Kim and Im, 2004].

The effects of bed temperature on gas composition and calorific value of woodchip are shown in Fig. 4. At this experiment, the feed rate of solid was 100-140 kg/h and the oxygen rate was 24-30 m^3/h. The heat needed for gasification reaction was derived from the combustion reaction of some of woodchip and RPF, so the composition of CO_2 was higher than steam gasification [Lee et al., 2001; Ko et al., 2001]. Also, CO_2 concentration of biomass gasification was higher than that of RPF because a shift reaction might occur.

The average gas composition of partial oxidation of woodchip is CO: 34.4%, H_2: 10.7%, CH_4: 6.0%, CO_2: 48.9% and that of RPF is CO: 33.9%, H_2: 26.1%, CH_4: 10.7%, CO_2: 29.2%. The calorific values of produced gas of biomass and RPF are 1,933 kcal/Nm^3, 2,836 kcal/Nm^3, respectively. At the biomass experiment, the weight fractions of gas, liquid and solid were 89.6, 4.8, 5.6, respectively.

The effect of bed temperature on caloric value of produced gas is shown in Fig. 5. As shown in Fig. 4, the sum of CO and H_2 gas concentration of woodchip and RPF was over 40%. These values are lower than other gasification results used steam gasification reaction because partial oxidation reaction was occurring in this reactor [Lee et al., 2001; Ko et al., 2001; Kim, 2003]. Also, the caloric value of produced gas decreased with an increasing bed temperature because the combustion reaction becomes larger than the gasification reaction. At the experiments of RPF, the effect of bed temperature on caloric value shows the same trend as seen in the plot. However the solid/oxygen ratio had the maximum value as shown in Fig. 6.

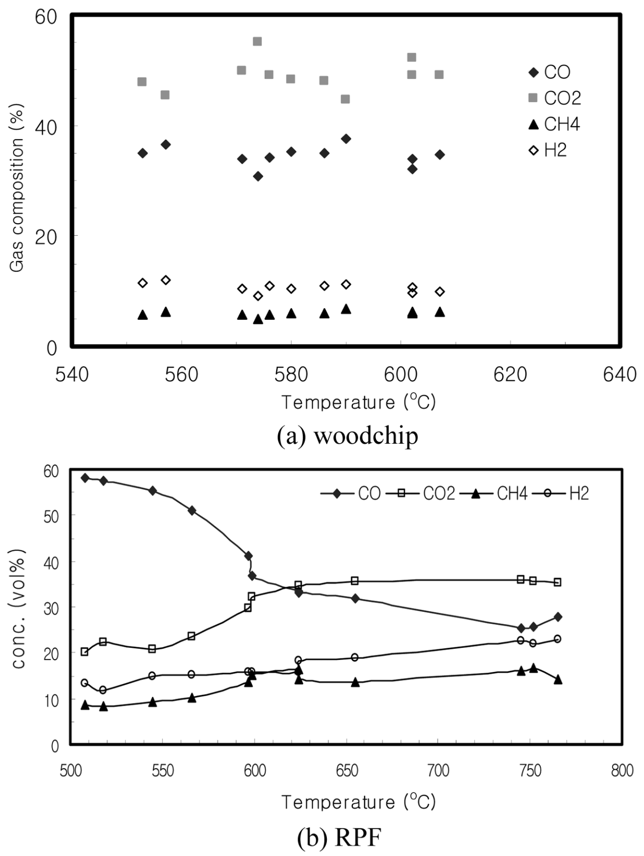


Fig. 4. Effect of bed temperature on gas composition (a) woodchip (b) RPF.

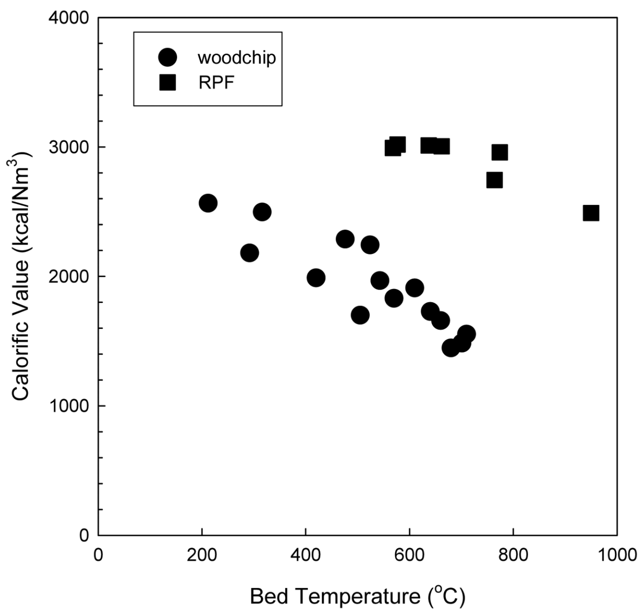


Fig. 5. Effect of bed temperature on calorific value of the produced gas.

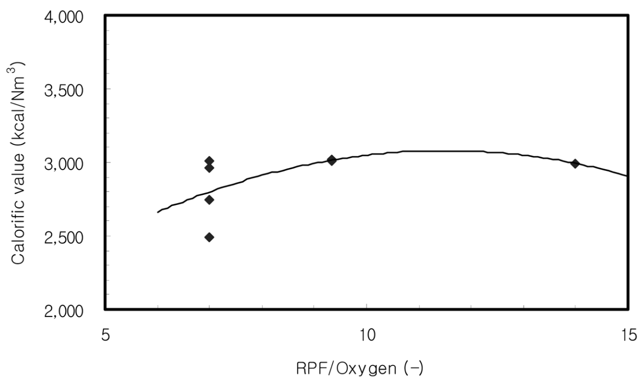


Fig. 6. Effect of RPF/O_2 ratio on calorific value of the produced gas.

(a) Air

(b) Oxygen

Fig. 7. Photograph of flame in burner using (a) air (b) oxygen as oxidant.

The cold gas efficiencies of RPF gasification were about 60% due to oxidation reaction.

The effect of solid/oxygen ratio on calorific value at RPF gasification experiments is shown in Fig. 6 and the photographs of flame of syngas are shown in Fig. 7. The effect of solid/oxygen ratio is quite different from that of bed temperature. In the RPF gasification experiments, the maximum value was 3,100 kcal/Nm^3 at solid/oxygen ratio: 7. In the biomass gasification experiments, maximum calorific value was 2,300 kcal/Nm^3 at solid/oxygen ratio: 15. It might be caused by different shape and components.

As can be seen in Fig. 7, the flame with oxygen input is more vigorous and stronger than that with air input [Na et al., 2003; Min et al., 2005]. However the syngas from air-blown gasification could be used via lean gas burner, stirring engine and so on. If 10 wt% of domestic combustible waste was used for resources in waste gasification processes, the production quantities of synthesis gas could be 1.38×10^9 Nm^3 from the data based on this study. If synthesis gas from wastes gasification was used for power generation, the production cost could become about 23 won/kWh, so the waste gasification process might have suitable economic value.

CONCLUSION

The gasification characteristics of combustible wastes, such as woodchip and RPF, were determined in a 5 ton/day fixed bed gasifier (1.2 m I.D. and 2.8 m high). The calorific values of the produced gas decreased with an increase of bed temperature because the combustion reaction happened more actively. The average gas composition of partial oxidation of woodchip is CO: 34.4%, H_2: 10.7%, CH_4: 6.0%, CO_2: 48.9% and that of RPF is CO: 33.9%, H_2: 26.1%, CH_4: 10.7%, CO_2: 29.2%. The average calorific values of produced gas were about 1,933 kcal/Nm^3, 2,863 kcal/Nm^3, respectively. The maximum calorific values were 3,100, 2300 kcal/Nm^3 because of different shape and components. If the gasification process of combustible wastes is used in power generation, the production cost may be about 23 won/kWh and the process might have suitable economic value.

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