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Experimental Study on Gasification of Biomass Using a Pebble Bed Slagging Gasifier

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Abstract

A pebble bed gasifier is composed of entrained flow section and packed bed section of ceramic balls (pebble bed section), and it has three main features: high efficiency of slag capturing; assurance of long reaction time; and thermal buffer function of the pebble bed. High temperature air is used as an oxidant to obtain high enough temperature inside of the gasifier to melt ash and realize tar free gasification. Two kinds of biomass samples were used as fuels in the gasification experiments. These were dried wood chips and carbonized fowl droppings, corresponding to high and low volatile matter fuel, respectively. It was shown that the carbon conversion rates were 96% and 80%, the cold gas efficiencies were 62% and 53% and the HHVs were $5.49\text{MJ/m}^3\text{N}$ and $3.50\text{MJ/m}^3\text{N}$ for each biomass sample, respectively.

Keywords: Biomass, Gasification, Carbon conversion rate, Cold gas efficiency

Introduction

As a new source of energy, biomass has been a attracted research subject. By using the method of gasification, we have been carrying out the research on high efficiency energy extraction from biomass resources. The system employed in our study is called MEET (Multi-staged Enthalpy Extraction Technology) which is shown in Fig. 1.

A high temperature air is used as an oxidizer in this system. Conventionally, in order to obtain syngas of high HHV, oxygen is used as an oxidizer. But if the oxygen is used as an oxidizer, costly equipments and energy are necessary to produce oxygen. Consequently, the using of a high temperature air as an oxidizer is one of the characteristics of the MEET system. Another feature is that a pebble bed gasifier where ceramic ball fixed bed

Fig.1 Concept of the MEET system

is installed under an entrained flow section is employed. The ceramic balls are called “pebbles”. Three functions are expected for the pebble bed gasifier: 1) high

efficiency slag capturing, 2) enhancement of gasification, 3) thermal stabilization. Figure 2 shows a schematic illustration of the pebble bed gasifier^[1]

Fig2. Concept of a pebble bed gasifier

Equipment

The first MEET system used in our experiments is called MEET-I facility, which is shown in Fig.3. It consists of a pebble bed gasifier, a solid fuel feeder, a steam feeder, a filter, a heater, a water cooler, an induced draft fan (IDF) and an air compressor.

Fig.3 Schematic of the MEET-I facility

The most important components among these is the pebble bed gasifier.^[2] The pebble bed is made of 30 ceramic balls of 50 mm in diameter. The structure of the pebble bed gasifier is shown in Fig. 4.

Operation

To achieve the high temperature needed in gasification, we preheated the gasifier by using natural

gas. For protecting the gasifier, the preheating rate was limited to 400~500 °C/h, which was controlled by monitoring the flow rate of natural gas. When the temperature of the bottom section of the gasifier exceeded the melting point of the ash of solid fuels, we shut down supply of natural gas and put the solid fuels into the gasifier. At the beginning of experiments, the air ratio was greater than 1.0 so that the solid fuel can be combusted completely until the temperature of the gasifier became stable. By controlling the air and steam flow rates, the gasification experiment was carried out. At the same time, the temperature in the gasifier was measured by thermocouples.

Properties of fuel

Two kinds of biomass samples were used as fuels in the gasification experiments. These were dried wood chips and carbonized fowl droppings, corresponding to high and low volatile matter fuel, respectively. The properties of the fuels are given in Table 1.

Table 1. Properties of Fuel

		Wood Chips	Carbonized fowl droppings
Proximate Analysis			
Moisture	wt%	7	3
Ash	wt%(dry)	0.6	34.6
Volatile Matter	wt%(dry)	83.4	21.3
Fixed Carbon	wt%(dry)	16	44.1
Total (dry)		100	100
HHV	MJ/kg	20.0	18.1
LHV	MJ/kg	17.2	16.8
Ultimate Analysis			
C	wt%(dry)	51	48.3
H	wt%(dry)	6.1	2.1
N	wt%(dry)	0.1	3.9
O	wt%(dry)	42.3	10
Cl	wt%(dry)	0.1	1.1
S	wt%(dry)	0.1	0.6

Results and discussion

Based on the analyzed value of fuels, no steam was added in gasification experiments for wood chips because they contain much water. Moreover, they contain so much volatile matter in the fuel that it is easy to be gasified. Consequently, the gasification experiments were carried out under the low air ratio. Oppositely, in the experiments using carbonized fowl droppings which contain little volatile matter and water, it is expected that gasification is difficult. So 2kg/h steam was supplied into the gasifier and the gasification experiments were carried out under a relatively high air ratio.

First, the gasification experimental results of wood chips are shown in Table 2.

Table 2 Experimental conditions and results of wood chip gasification

		T1	T2	T3	T4
Fuel	kg/h	7.0	7.0	7.0	10.0
Air	m ³ N/h	7.3	8.9	8.9	14.0
Air Ratio		0.31	0.36	0.36	0.37
H ₂	dry%	14.59	12.92	12.65	11.59
O ₂	dry%	0.00	0.00	0.00	0.00
N ₂	dry%	50.51	53.09	54.47	56.27
CH ₄	dry%	2.24	2.16	1.76	1.68
CO	dry%	21.72	20.23	19.37	18.22
CO ₂	dry%	10.93	11.59	11.74	12.23
HHV	MJ/m ³ N	5.49	5.06	4.76	4.44
C.C.R.	%	90	96	89	86
C.G.E.	%	62	62	57	51

To evaluate the gasification efficiency, carbon conversion rate (C.C.R.) and cold gas efficiency (C.G.E.) are determined by eqs. (1) and (2).

$$\text{C.C.R.} = \frac{\text{Total Amount of Carbon in Syngas}}{\text{Total Amount of Carbon in Solid Fuel}} \times 100\% \quad (1)$$

$$\text{C.G.E.} = \frac{\text{Total Heating Value of Syngas}}{\text{Total Heating Value of Supplied Fuel}} \times 100\% \quad (2)$$

In order to calculate the C.C.R., it is necessary to know the flow rate of the syngas. But it is difficult to measure the flow rate of the syngas directly because the gas composition fluctuates. Therefore, the nitrogen gas balance method was used in the calculation of the syngas flow rate with following assumptions.

- 1) Mole flow rate of nitrogen gas at the entrance of the gasifier is as same as that at the exit of the gasifier.
- 2) The only substances supplied into the gasifier are the fuel, air and steam.
- 3) The formation of nitrides can be ignored.

It can be seen from Table 2 that in each experiment, syngas containing heating value above 4.18MJ/m³N was obtained and the highest HHV is 5.49MJ/m³N. The average value of the C.C.R. was greater than 90% and the maximum value was 96%. The average value of the C.G.E. was about 57% and the maximum value was 62%. Moreover, it can be seen that as the air ratio increased from 0.31 to 0.37, the amount of combustible gases such as H₂, CO and CH₄ decreased (Other of C_mH_ns are not generated).

Secondly, the gasification experimental results of carbonized fowl droppings are shown in Table 3. Under the condition of 0.49 of air ratio, although the carbonized fowl droppings contained low volatile matter, a syngas containing as high as 3.50MJ/m³N of HHV was obtained. The maximum value of the C.C.R. was as high as 80%. The maximum value of the C.G.E. was about 53%. It is considered that because of the presence of the pebble bed, carbonized fuel was captured on the pebble bed, which increased the residence time of the fuel in the gasifier.

Figure 5 shows the difference of temperature distribution in the gasifier for the two fuels during the gasification experiments. In the case of wood chips, the main reaction took place in the entrained flow section.

Fig.4 Gasifier of the MEET-I facility

The highest temperature area in the gasifier located in the entrained flow section. On the contrary, in the case of carbonized fowl droppings, the main reaction took place in the pebble bed section. The highest temperature area in the gasifier located in the pebble bed section.

Table 3 Experimental conditions and results of carbonized fowl dropping gasification

		T1	T2
Fuel	kg/h	7.7	7.7
Air	m ³ N/h	13.9	13.9
Steam	kg/h	2	2
Air Ratio		0.49	0.49
H ₂	dry%	9.5	8.1
O ₂	dry%	0.0	0.0
N ₂	dry%	61.8	63.9
CO	dry%	17.9	16.8
CO ₂	dry%	10.6	11.1
CH ₄	dry%	0.1	0.0
HHV	MJ/m ³ N	3.50	3.15
C.C.R.	%	80	76
C.G.E.	%	53	47

Fig. 5 Temperature distribution

Conclusion

We have carried out gasification experiments of two kinds of fuel successfully. The syngas that is usable for gas engine generator has been obtained. As the results, in the experiment for wood chips, the carbon conversion rate of 96%, the cold gas efficiencies of 62% and the HHV of 5.49MJ/m³N were obtained respectively. In the experiment for carbonized fowl droppings, the carbon conversion rate of 80%, the cold gas efficiencies of 53% and the HHV of 3.50MJ/m³N were obtained respectively. When we changed the low volatile matter

fuel to the high one, the main reaction area moved from the entrained flow section to the pebble bed section. This fact demonstrates the function of the pebble bed.

References

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