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Characteristics of air-blown gasification in a pebble bed gasifier

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Abstract−High temperature air-blown gasification is a new concept to utilize the waste heat from gasifier that is called multi-staged enthalpy extraction technology. This process was developed to solve the economic problems due to air separation costs for the oxygen-blown as a gasifying agent. In this study, we have constructed a pebble bed gasifier and operated it by controlling the pebble size and bed height with three different types of coal (Kideco, Datong and Drayton coal). As a result, we can produce syngas with a calorific value of 700 kcal/Nm^3 at an air temperature of 650 °C; the performance of high temperature air gasification was strong in the order of Kideco coal, Datong coal and Drayton coal. Also, from the data of the exterior analysis of slag that is attached to the surface of pebbles, we can know that the iron component is considerably high. This means the increase in restored metallic iron component seems to contribute to the solidification of slag.

Key words: Gasification, Pebble Bed, Solid Waste, Coal, High Temperature Air

INTRODUCTION

High temperature air blown gasification, called a Multi-staged Enthalpy Extraction Technology (MEET), is a new method to utilize air as an oxidizing agent for gasification. The existing gasification method utilizing pure oxygen as a gasifying agent requires costly oxygen production plants even though it provides syngas with high calorific value. To overcome the economic problem, the MEET system has been developed in Japan for the first time as a part of CREST (Core Research for Evolutional Science and Technology) [Yoshikawa, 2000; Kato, 2002]. The purpose of MEET is to develop an economical, compact, and highly reliable power system that can respond to any low grade hydrocarbon fuel with almost the same machinery formation and generate electricity efficiently reducing environmental burdens produced from combustion [Pian and Yoshikawa, 2001; Young and Pian, 2003].

High temperature air-blown gasification is very special in the sense that it focuses on small and medium plants by establishing a pebble bed, which makes it possible to keep heat. A high temperature air-blown gasifying power system is to filter off pollutants from syngas produced by the gasification process with high temperature air that is heated over 1,000 °C and then the syngas is reburned by using high temperature air to operate a low NO_X combustion system operating steam turbines or gas turbines.

Fig. 1 shows the high temperature air-blown gasification system. Fuels such as coal, residue, and wastes change into syngas through gasification process inside of the gasifier. A gasifying agent includes steam or the sole form of air with temperature about 1,000 °C. The syngas is scrubbed after being cooled down through heat exchanges. Some of the scrubbed syngas is used to heat air (gasifying agent) in high temperature, and the rest is used as fuel for various purposes. Among solid fuels, ash is extracted as a form of slag through being melted inside the gasifier. As such, the method, which utilizes high temperature air and pebbles, maintains the gas temperature over the melting point of ash. Pebble bed gasification reactor, which is a kind of the slagging gasifier that gasifies inflammables and melts ash, is the most important essential technology in the MEET system [Choi et al., 2001a, b, c].

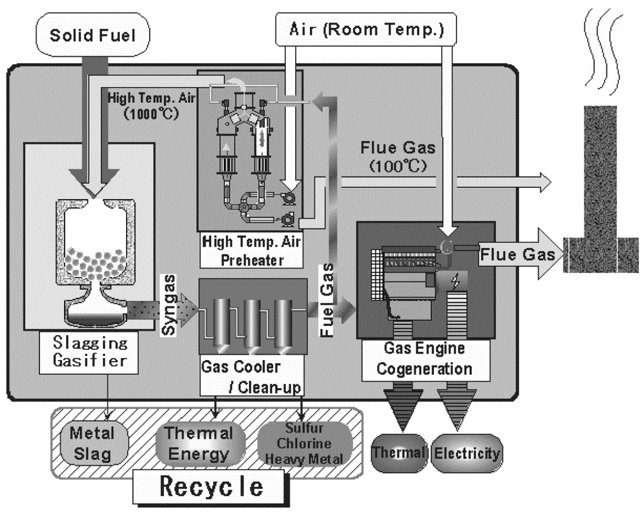

Fig. 1. Syngas production and utilization system by MEET method.

In this research, a high temperature air-blown gasifier was developed and some gasification experiments using three different kinds of coal were conducted to secure useful information of this type of gasification process.

EXPERIMENTATION

1. Samples

Samples used in this research were three kinds of coal. Table 1 shows the results of the sample analysis.

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Table 1. Results of the sample analysis

Sample	Ultimate analysis (wt%)					Proximate analysis (wt%)				H.H.V (kcal/kg)
	C	H	O	N	S	Moisture	V.M	Ash	(F.C)	
Datong	74.77	4.26	0.82	0.70	10.81	10.58	29.18	8.64	51.60	6,580
Drayton	74.60	4.61	1.67	0.57	6.39	5.45	29.31	12.16	53.08	6,820
Kideko	72.45	4.92	1.14	0.06	19.53	18.15	39.97	1.90	39.63	6,270

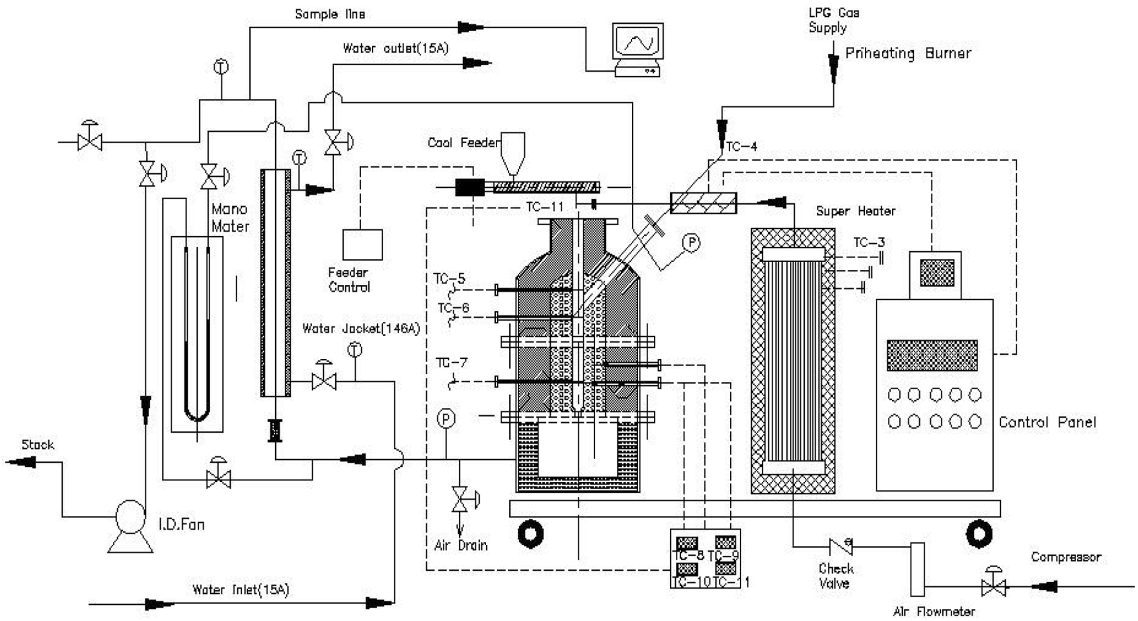


Fig. 2. P&ID for the high temperature air-blown gasifier.

2. Apparatus

Lab. scale high temperature air-blown gasifier consists of high temperature air preheater, high temperature air gasifier, coal feeder, and controller. P&ID for the high temperature air-blown gasifier is shown in Fig. 2. In the high temperature air-blown gasifier, a packed bed with 10 mm, 30 mm ceramic balls is established at the lower part. Four thermocouples to measure the inner temperature and three thermocouples to measure the temperature of refractory are used. The air preheater is possible to heat air to maximum 1,000 °C and the samples feeder applies a screw feeder. The high temperature syngas is cooled down in the latter part of gasifier. In the process of sampling gas analysis, cyclones and dust collectors are established.

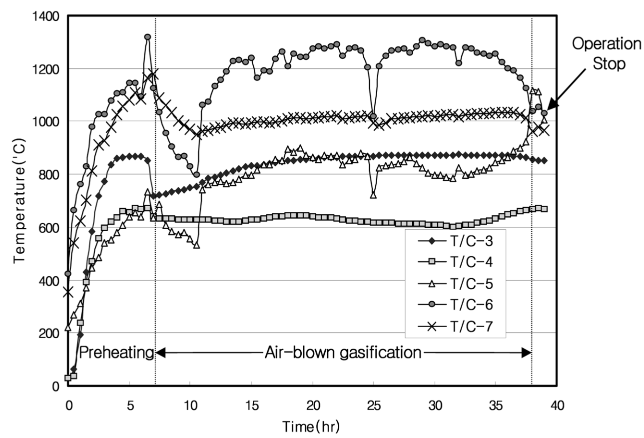


Fig. 3. Temperature distribution inside of the gasifier.

RESULT AND DISCUSSIONS

1. Temperature Distribution

The temperature distribution was measured on several measuring points. The first and second temperatures of high temperature air, supplied as the gasification agents, were measured. Also, the temperature of the upper and center part of entrained bed and the temperature of the pebble part was measured. By using the first and second heating furnace with electric heating method, high temperature air could be heated up to 600-1,000 °C within air amount of 10-15 Nm^3/h. In this research, the high temperature air was able to be heated up to 600-800 °C due to a limit of the heater.

The measurement for the inside temperature of the gasifier was performed by an R-type heat thermocouple, which passes through refractory. Especially, the temperature of the pebble bed was selected as an operating condition for slag melting. The inside temperature of gasifier was heated to 1,200 °C for reaction zone and 1,000 °C for pebble bed by an LPG burner. After obtaining enough high inside temperature of gasifier, the gasification was performed by feeding coals. Under normal operating conditions, as shown in Fig. 3, the temperature inside of the gasifier showed various temperatures from the highest to the lowest, the order of the upper part, pebble part

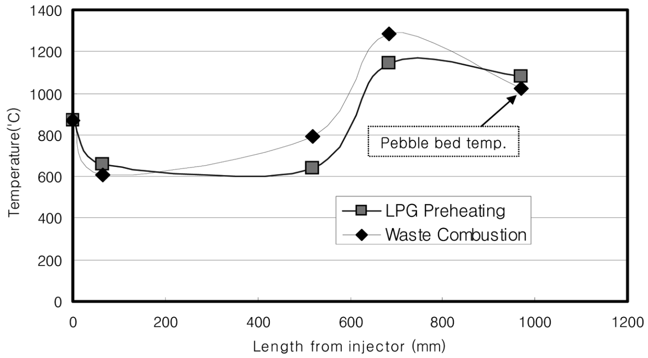
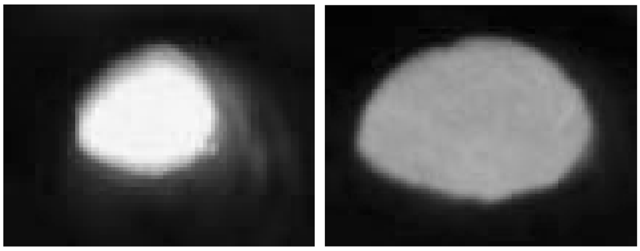


Fig. 4. Temperature distribution inside of the gasifier during LPG preheating and coal gasification.



(a) LPG burning (b) Flame of coal gasification

Fig. 5. The comparison between the flame of LPG burning and that of coal gasification.

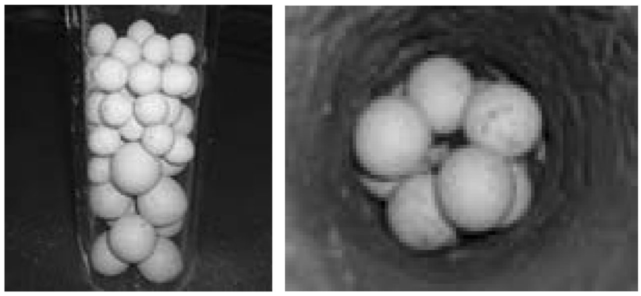


Fig. 6. Packed pebble bed.

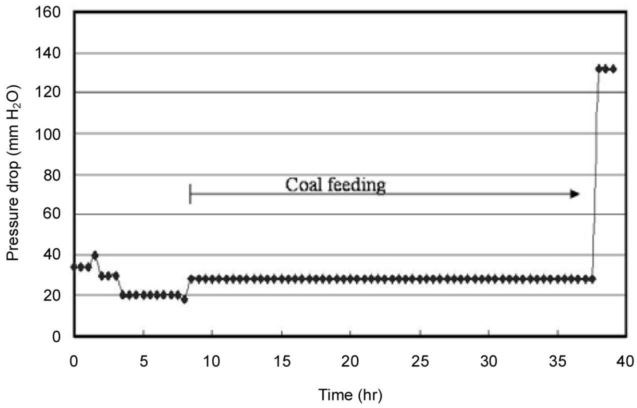


Fig. 7. Pressure drop measured at pebble bed.

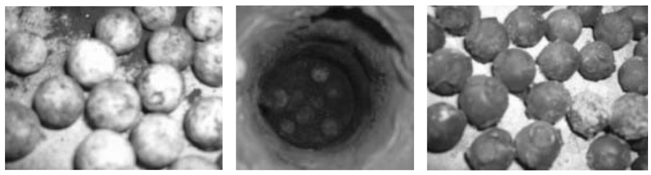


Fig. 8. Clogged pebble bed caused by the oversupplied coal.

and middle part. The reason why the temperature at TC-5 and TC-6 changes abruptly is that during the experimental time interval between 5-10 hrs, we start to supply coal after preheating gasifier by using LPG. So, the temperature of the gasifier decreases and becomes higher due to the coal combustion.

Fig. 4 shows the temperature distribution inside of the gasifier according to the length from injector during LPG preheating and coal gasification. When preheated by LPG, the temperature distribution at the upper part of gasifier was stable. During gasification, the temperature of pebble bed was lower than that of the middle part. However, it did not mean that the temperature of pebble bed was low. Rather, it seemed the measuring value was lowered under the actual value as the melted non-reactive materials and ashes were accumulated on the thermocouple. This result was also expected from the measuring value of the temperature collapsed on the non-penetrated wall. The measured temperature was deemed to be at least 300 °C lower than actual temperature.

The comparison between the flame of gas preheating and that of coal gasification is shown in Fig. 5. While the flame of gas burning was generally equalized, the flame of coal gasification showed the flame from solid particles and became more distant from the nozzle as air amount increased.

2. Pressure Loss in Pebble Bed

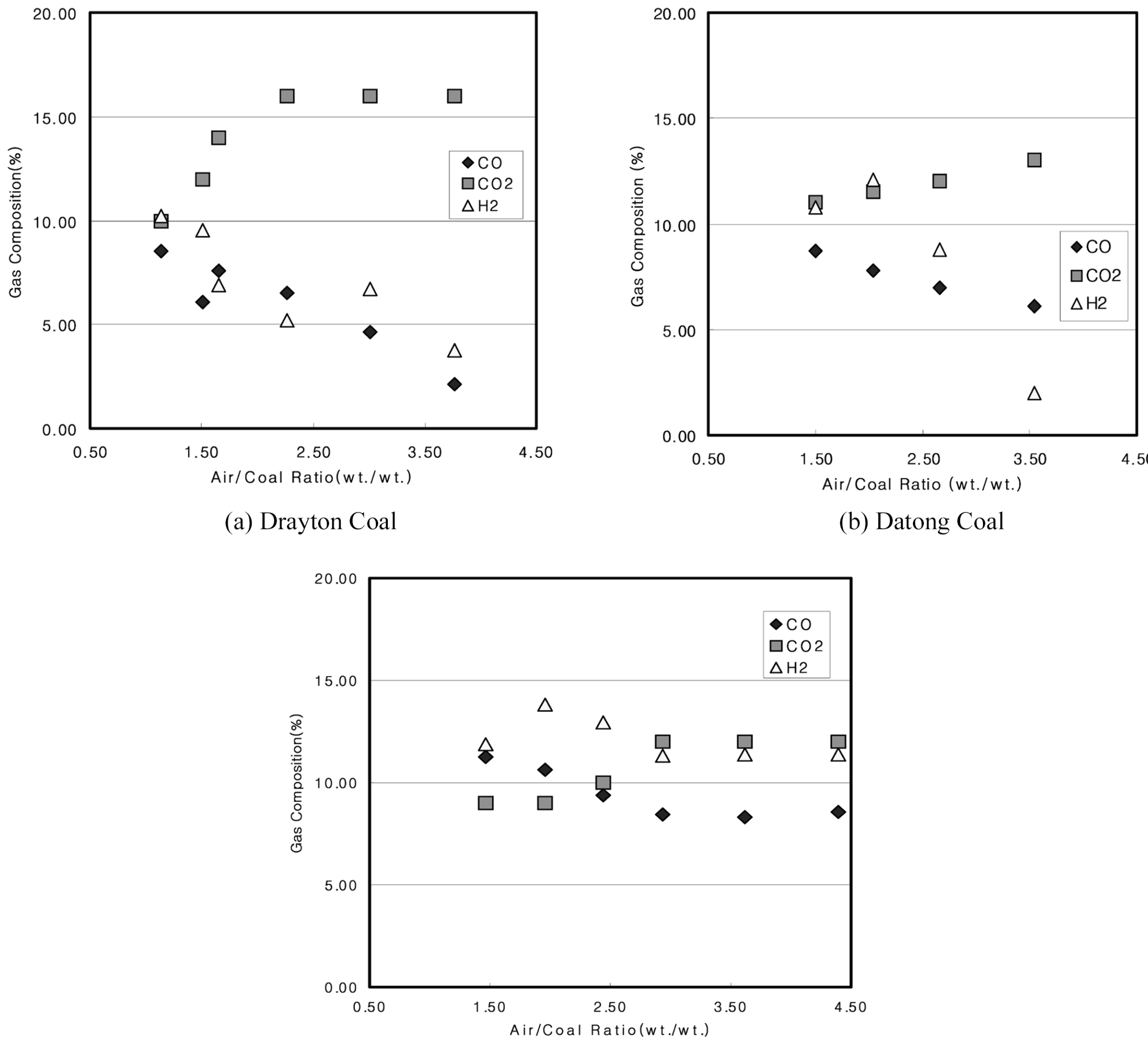
The lower part of the gasifier maintained conical shape that prevents pebbles from falling. Big pebbles with the diameter 3 cm balls were packed making three beds in the bottom section, and small pebbles with the diameter 1 cm balls were packed making additional four beds on the big pebbles, as shown in Fig. 6.

Because the pressure drop in the pebble bed acted as an exit to syngas that is generated in a reactor, there would be a problem with the reliability of operation if it was clogged. So, the pressure difference between the upper part and the lower part of pebble beds was measured. As shown in Fig. 7, when preheated with LPG, the pressure drop maintained 20 mmH_2O. When coals are supplied, the pressure drop increased a little.

Under the normal operating conditions, the pressure drop was maintained at 25 mmH_2O, but when slag was not melted sufficiently or coal was oversupplied, the pressure drop rose so quickly that it caused clogs. Therefore, in the case that the appropriate coal supplies were not maintained on the condition of ventilation with ID Fan, they caused the interruption of gasifier operation. The situations showing the oversupplied coals or solidification of melted slag are in Fig. 8.

3. Syngas Production

Gasification for three kinds of coal was performed. In gasification, the preheated air temperature reached 800 °C, but the preheated air is supplied at 650 °C due to the loss of heat, etc. The coals used in the experiment were Drayton, Datong, and Kideco coals, and the results of syngas analysis are shown in Fig. 9. The



(a) Drayton Coal (b) Datong Coal

(c) Kideco Coal

Fig. 9. Changes of syngas production according to the air amount per samples.

amount of coal supply was maintained at 1 kg/h, and the amount of air supply was one to four times of coals in terms of weight.

As the air amount increased, the distribution and combustibility of coal particles improved. That made the amount of CO_2 increase while the amounts of CO and H_2 that were combustible components decreased. In this experiment, CO and H_2 were 5-10% and 5-15%, respectively. This result was lower than the result of another experiment, which was performed with Datong coal at 900 °C (H_2 and CO were 16.1% and 23.1%, respectively). In thermodynamics, the reaction of char-CO_2 and char-H_2O is endothermic, which is made within the mutually exclusive temperature, so as the temperature goes up, the reaction of char-CO_2 becomes stronger than that of char-H_2. Therefore, it is interpreted that in case of the low preheated air temperature, the amount of H_2 relative to CO is made much more.

$$C+CO_2 \rightarrow 2CO \qquad \Delta H=172.6\ kJ/mol$$
$$C+H_2O \rightarrow CO+H_2 \qquad \Delta H=131.4\ kJ/mol$$

The calorific changes of syngas, generated by the result of experiments with each kind of coal, are shown in Fig. 10.

When the ratio of air was maintained 1.5-2.5, the calorific value of syngas was 500-700 kcal/Nm^3. In order to increase the syngas calorific value to 800-1,000 kcal/Nm^3 afterwards, it seems necessary to increase the air temperature. According to the experiment, the performance of gasification was strong in the order of Kideco coal, Datong coal and Drayton coal. This result was the same as the reactive measuring result under high temperature TGA.

4. Slag Formation

Fig. 11 shows the phenomena examined from the lower sight glass and the state of retrieved slag and pebbles. It helps to understand the flowing nature of melted slag during high temperature air gasification process.

Table 2 shows the results of analysis on the exterior of slag, which is attached to the surface of pebbles.

From the table, we can guess that as the low volatile ingredients of ash components, such as Na_2O, K_2O, decrease and SiO_2 and Al_2O_3

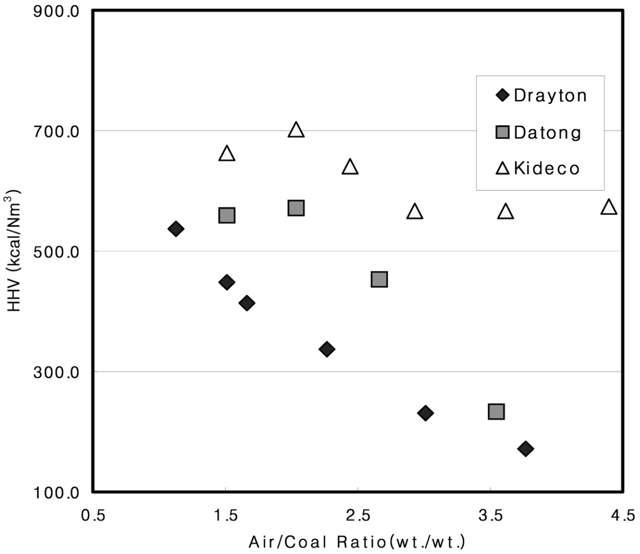


Fig. 10. The calorific changes of syngas according to the air amount of each kind of coal.

Fig. 11. The falling state of melted slag.

Table 2. The analysis of the exterior of slag attached to the surface of pebbles

SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	TiO_2
35.71	16.15	30.38	14.45	2.24	1.06

increase, it changes into aluminous silicate compound. From the data of the exterior analysis of slag that is attached to the surface of pebbles, we can know that the iron component is considerably high. Therefore, the increase in restored metallic iron component seems to contribute to the solidification of slag. In addition, considering the shape of slag that is attached to pebbles after cooling, ashes or unburned matters left in syngas seem to be attached to the surface of pebbles by the inertia collision.

CONCLUSION

The comprehensive results of this research with the experiment of high temperature gasification in a pebble bed gasifier are as follows:

1. With the small pebble bed gasifier that was made for this experiment, a performance property test on the basis of each kind of coal and the amount of air was carried out.
2. By controlling the pebble size and bed height, the proper pressure drop and operational conditions for slag formation could be understood.
3. An electric heater was used to make high temperature air, and syngas with a calorific value of 700 kcal/Nm^3 could be made by utilizing high temperature air of 650 °C.
4. The calorific value of syngas increased in the order of Drayton coal, Datong coal and Kideco coal, which was compatible with the reactivity measured in high temperature using TGA.

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