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High temperature air-blown gasification of Korean anthracite and plastic waste mixture

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Abstract−Korean anthracite is too high in ash contents and low in calorific value to be used as an industrial energy source, the demand for anthracite has rapidly decreased and its competitiveness weakened. To overcome the problem, a mixture of Korean anthracite and plastic wastes low in ash and high in calorific value was manufactured. A 1.0T/D fixed bed gasification process was developed to understand the gasification characteristics of the mixtures and secure operation technology using Korean and Chinese anthracite. For the Korean anthracite, the syngas composition and heating value are varied from 10 to 20% and from 300 to 800 kcal/Nm^3 as a function of steam/air/fuel ratio. Therefore, it is concluded that Korean anthracite is hard to gasify because of low reactivity. For the Chinese anthracite low ash content and higher heating value than domestic anthracite, the syngas composition was maintained at about 20-40% and the calorific value was 800-1,300 kcal/Nm^3. A reformer using high-temperature air/steam was installed just after the gasifier to combust and convert tar and soot into syngas. We confirmed that the amount of generated tar and soot showed a salient difference after running the reformer. In the future, gasification experiments of manufactured mixtures of anthracite and plastic waste using 1.0T/D fixed bed gasifier will be performed.

Key words: Korean Anthracite, Fixed Bed Gasifier, Syngas, Calorific Value

INTRODUCTION

The use of anthracite, the only natural resource that Korea has mostly processed into briquettes for private consumption, began to decrease rapidly in the 1990's, and in place of briquettes made from simple molding of anthracite, which has many problems, such as the inconvenience of handling and ignition, low thermal efficiency and emission of pollutants, people began to prefer using clean and convenient gas and oil. Furthermore, as the Korean anthracite is too high in ash content and low in calorific value to be used as an industrial energy source, the demands for anthracite have rapidly decreased and its competitiveness weakened, putting the domestic coal industry in peril. Consumption of the Korean anthracite recorded a negative growth rate in the 13% range in the 1988-2001 period, falling from 25.6 million tons in 1988 to 4 million tons in 2001. To increase the consumption of the Korean anthracite, the development of a technology to facilitate the use of large quantities through conversion of coal into processed fuel easy to handle and ignite and high in thermal efficiency is urgently needed.

In addition, the disposal of wastes, which are emerging as social issues in connection with recent environmental issues, is largely classified into landfill, incineration, and recycling. As waste disposal, which used to depend mostly on landfills, is facing the difficulty of securing a landfill site owing to the opposition of local residents, interest in recovery of heat energy through incineration, and turning wastes into resources through pyrolysis and gasification has been on the increase. Recycling of wastes through incineration, pyrolysis and gasification is essential because of the extremely high prices of raw materials in Korea that imports most of its energy sources. However, it has many restrictions: the difficulty of controlling combustion due to the inconsistent characteristics of wastes, the emission of large quantities of pollutants and the difficulty of transportation due to its existence in the solid state. Accordingly, recovery of recycled materials from wastes including plastic is increasing, but the actual recycling ratio is not quite up to the mark.

In consideration of the difficulty of utilizing Korean anthracite and plastic wastes, a plan to use a fuel mixing the Korean anthracite and plastic waste is being presented. In other words, the Korean anthracite is difficult to use owing to its high ash content and low calorific value, but a plan to make mixtures with plastic waste with almost no ash content and high in calorific value and utilize the syngas (H_2+CO) obtained from gasification process is being reviewed. Currently, Germany's Schwarze Pumpe's SVZ process is using the syngas created through gasification of the mixtures of anthracite and plastic waste in place of city gas. Gasification of plastic wastes may cause several operational troubles as during gasification it is difficult to input raw materials and large quantities of tar and soot are generated and accumulated inside the reactor, the cyclone and the gas scrubbing system. To secure air-permeability as a solution to the channeling phenomena likely to occur during gasification due to slagging caused by plasticity after heating, plastic waste mixed with anthracite containing large amounts of ash is manufactured and the gasification plant is operated stably. The high quantities of dust generated during gasification can be re-combusted, gasified and then improved by a steam reformer using high-temperature air [1]. Fig. 1 illustrates the process flow diagram of the gasification system that includes a reformer using high-temperature air. The gas-

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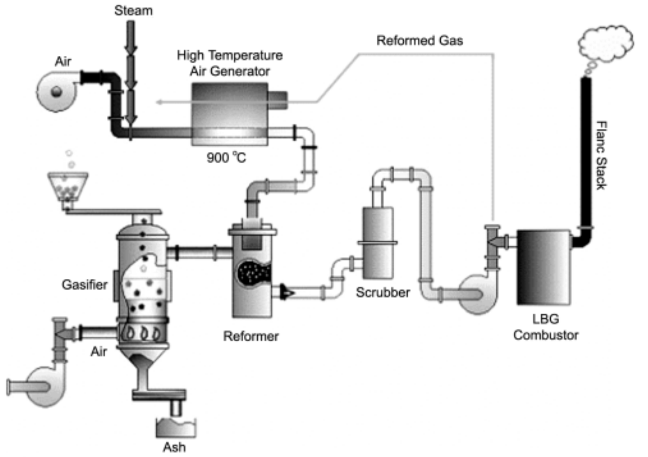


Fig. 1. PFD of the fixed bed gasification system including a reformer using high-temperature air.

Fig. 2. View of the gasification system including a reformer using high-temperature air.

ification and reforming process using high-temperature air shown in the figure is one of the distributed power generation technologies researched intensively by Prof. K. Yoshikawa of Tokyo Institute of technology, Japan. High temperature air blown gasification, called a Multi-staged Enthalpy Extraction Technology (MEET), is a new method to utilize the air as an oxidizing agent for gasification [2,3]. 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). 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.

Accordingly, in this study, to create demand for the Korean anthracite, a mixture of Korean anthracite and plastic wastes low in ash and high in caloric value was manufactured and its reactivity was assessed. A 1.0T/D fixed bed gasification process was developed to understand the gasification characteristics of the mixtures and secure operation technology using Korean and Chinese anthracite [4]. In the future, the gasification experiments of manufactured mixtures of anthracite and plastic waste using 1.0T/D fixed bed gasifier will be performed. As a result, energy sources of Korea lacking in natural resources can be diversified and stabilized. In consideration of the fact that waste and coal gasification technology for power generation is hard to apply because of low technical reliability and vast amounts of initial investment, development of small-scale gasification application technology like the one described in this study is thought to be used as a core technology in the age of distributed power [5-7].

EXPERIMENTAL

The high-temperature steam reforming gasification process is shown in Fig. 2. The main systems are feedstock supply hopper, a feedstock supply system, a high-temperature air/steam manufacturing system, the fixed bed gasifier, a high-temperature steam reformer, an unburned carbon recovery system, heat exchanger and a control and analysis system.

The characteristic of the reactor is the counter-current process according to which the fuel is supplied from the top to the bottom, and the gasification agent moves from the bottom to the top. The inside of the reactor is insulated by refractory (thickness: 200 mm), and in the top, middle and bottom of the wall thermocouples for measuring the reaction temperature and wall temperature are installed, and a sight glass for monitoring the internal state is installed. In the upper part of the reactor a belt transport system with load cells is installed, and in the lower part there is a grate for supplying the reactant bed support. Unreacted ash is discharged from the grate and retrieved from the chamber, and the syngas after gasification is discharged from the exit in the upper part.

The high-temperature steam reformer reactor is 1,160 mm long, and 410 mm in diameter, and insulated by refractory 150 mm thick. The lower part is filled with ceramic balls (30 mm*17ea) and used as the regenerative bed (height: 560 mm). Three thermometers are installed in the reformer, and the high-temperature air and steam is supplied from the top to the bottom so that they are mixed with the syngas. The reformed syngas goes through the dust collector, the heat exchanger and the scrubber, and then gets discharged by the ID Fan. In case soot and tar, included in the syngas manufactured in the fixed bed gasifier, are not discharged because of the clogging of the reformer or the dust collection system, a bypass pipe from the fixed bed gasifier to the scrubber was installed. As unreacted tar may occur in the syngas discharging pipe depending on the operating condition, a tar recovery chamber was installed before the ID Fan. The high-temperature air is made by heating the manufactured mixed gas or LPG. The high-temperature air manufacturing system is installed vertically, fuel is burned in the lower part and heat is exchanged with compressed air on the fin-type heating surface. This system is less expensive than the rotary-type heat exchanger developed by previous researchers, and capable of manufacturing high-temperature air, which is a plus. The overall system is monitored in the control room, which also is in charge of data logging. The air compressor and steam generator can be managed integratively as well. As for gas analysis, sample holes were installed

Table 1. Analysis of the Korean anthracite and mixtures

	Proximate analysis (wt%)				Elementary analysis (wt%)					Calorific value (kcal/kg)
	Moisture (M)	Volatile matters (V.M)	Ash (Ash)	Fixed carbon (F.C)	Carbon (C)	Hydrogen (H)	Nitrogen (N)	Oxygen (O)	Sulfur (S)	
Mixtures	2.94	82.99	6.87	7.20	66.20	8.38	0.71	17.837	0.003	7,220
Korean anthracite	12.19	5.76	25.53	56.52	67.70	1.61	0.78	3.77	0.61	5,310
Chinese anthracite	0.81	7.18	12.44	79.57	88.80	3.19	0.58	1.10	0.52	7,280

so that the characteristics of the mixed gas were measured inside the fixed bed reactor, at the exit of the gasifier and the exit of the reformer. The syngas was analyzed by the gas G/C analyzer after the moisture and dust of the sample gas was removed from the pre-processing system.

RESULTS AND DISCUSSIONS

1. Analysis of Mixtures of Feedstocks

The Korean anthracite and the waste plastic, used as fuel for the high-temperature air gasification system, were manufactured on a 50 : 50 basis. The analysis of the characteristics of the Korean anthracite used to make the mixtures and the manufactured mixtures are shown in Table 1. With regard to the elementary analysis of the mixtures, the amount of samples used for this analysis is very small, so they hardly represent the entire sample accurately. In general, the caloric value of the manufactured mixtures was approximately 7,220 kcal/kg.

To understand the ignition temperature and combustion characteristics of the Korean anthracite, waste plastic and the mixtures of Korean anthracite and waste plastic, a certain amount of samples were burned at 15 °C/min ascending temperature gradient up to 1,200 °C while air was injected, and the weight reduction changes according to temperature are illustrated in Fig. 3.

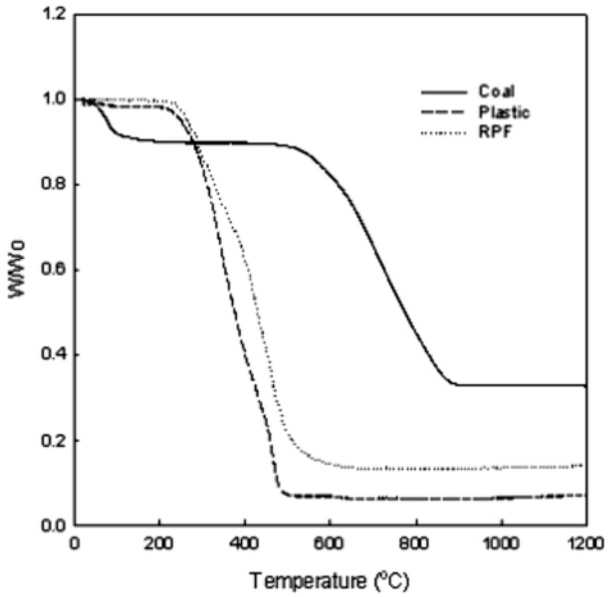


Fig. 3. Combustion characteristics of the Korean anthracite, waste plastic, and the mixtures of Korean anthracite and waste plastic.

In the case of the Korean anthracite used in this experiment, about 10% weight reduction occurred near 60 °C due to the evaporation of the moisture in the coal, and then weight was reduced by a small quantity of volatile matters. In general, in the case of bituminous coal, devolatilization occurs near 300 °C, and char combustion takes place near 400 °C. Meanwhile, since the Korean anthracite, used in this experiment, has less volatile matter than the bituminous coal, no clear devolatilization was observed. In addition, as shown in the above result, the Korean anthracite began to be burned near 500 °C, and the weight reduction ratio was 0.3 after the combustion reaction was over. So it is obvious that the ash content must account for about 30%. The waste plastic used in this experiment is greatly affected by the source and components, but according to the tendency identified in the TGA result, similar to the existing tendency of plastic pyrolysis, pyrolysis began near 300 °C, and the residue amounted to about 5-10%. In addition, the mixtures of Korean anthracite and waste plastic may vary in terms of the mixing ratio and components of each fuel; it showed pyrolysis characteristics similar to those of plastic, and the ash of the anthracite left about 15-20% residues after pyrolysis.

2. Results of the Gasification Experiment

For the initial operation in the fixed bed gasification experiment, Korean and Chinese anthracites were used in place of the mixtures of Korean anthracite and waste plastic. In general, in the case of plastic gasification, it is difficult to secure air permeability because of plastic slagging at a low temperature, so gasification is very difficult, and if the reformer does not work perfectly during operations, toxic gas may be discharged. So safety was taken into con-

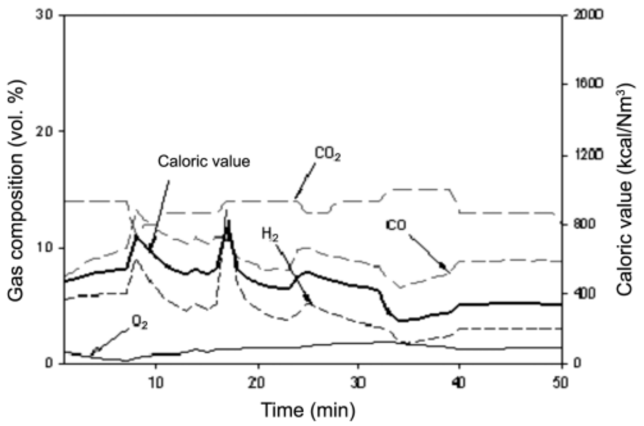


Fig. 4. Gasification results of Korean anthracite.

sideration in advance when decisions were made. Accordingly, for the gasification of the mixtures, two different types of coals were used to secure operation know-how for safe operations.

Experimental runs with two different coals were performed to study the effects of steam/air/fuel ratio on the composition and heating value of syngas. So, different operation conditions caused changes of syngas composition and heating value. A gasification experiment of Korean anthracite, which has high ash content and low heating value, was performed in advance. Fig. 4 shows the gasification result of Korean anthracite for syngas composition and heating value. In this result, syngas composition and heating value are varied from 10 to 20% and from 300 to 800 kcal/Nm^3 as a function of steam and air flow rate. Therefore, it is concluded that Korean anthracite is hard to gasify because of low reactivity.

Fig. 5 depicts the gasification result of china anthracite which has low ash content and higher heating value than domestic anthracite. As shown in the gas composition analysis of China coal gasification experiment by I/R analyzer in Fig. 2, syngas composition was maintained about 20-40% and the calorific value was 800-1,300 kcal/Nm^3. The peak of composition and calorific value shown at the lower part of the figure was the result of air and steam flow changes that were made to measure the change of gas composition to the ratio of air/steam. As a whole, we concluded the gasification experiment was performed stably.

Table 2 shows gas composition and calorific value that was derived from the experiment with Chinese coal by G/C analyzer. As shown in Table 2, at the early stage of gasification reaction, a large amount of methane was generated, but as experiment time went by, methane content decreased. That was why at the early stage of gasification reaction, thermal decomposition progressed at the upper part of coal bed, but as experiment time went by, the reaction of fixed carbon, oxygen, and steam became stronger than gasification by thermal decomposition because coal samples could not be continuously supplied due to the difficulty in ash discharge.

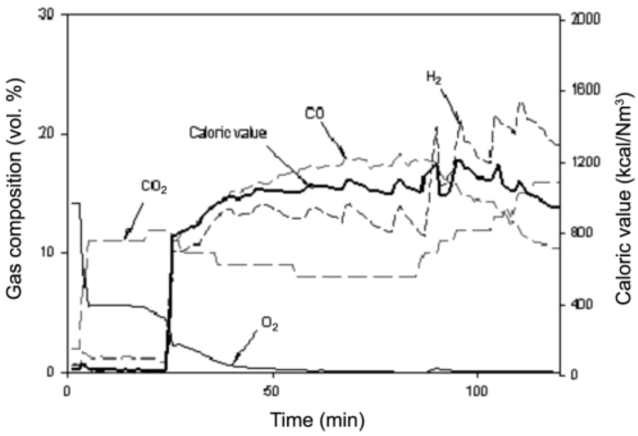


Fig. 5. Gasification results of Chinese anthracite.

The large quantities of tar and soot generated in the gasification experiment are obstacles to long-term operation of the system. Accordingly, in a reformer using high-temperature air/steam, the syngas generated from the fixed bed gasification process and the steam injected at the top are mixed so that the tar and soot are combusted and converted into syngas inside the reformer. The quantity and temperature of the syngas, generated by the fixed bed gasifier, had the greatest impact on the temperature at the reformer. The high-temperature steam and air at 900 °C produced by the high-temperature air manufacturing system were supplied to the reformer. The high-temperature air flow rate was 15-20 Nm^3/h, and the steam flow rate was 5-10 kg/h. The amount of generated tar and soot showed a salient difference after the reformer was run. As illustrated in Fig. 6, hardly any tar and soot was generated, which made operations difficult.

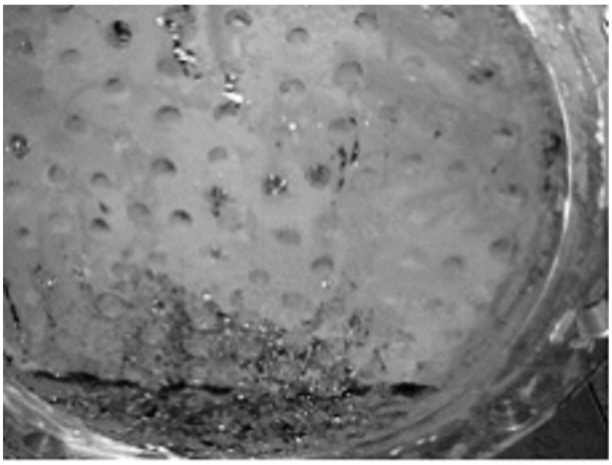
CONCLUSIONS

The Korean anthracite is too high in ash content and low in calorific value to be used as an industrial energy source, the demand for anthracite has rapidly decreased and its competitiveness weakened, putting the domestic coal industry on the verge of extinction. In this study, to create demand for the Korean anthracite, a mixture of Korean anthracite and plastic wastes low in ash and high in caloric value was manufactured and its reactivity was assessed, and a 1.0T/D fixed bed gasification process was developed to understand the gasification characteristics of the mixtures and secure operation technology using Korean and Chinese anthracite. A summary of the results is as follows:

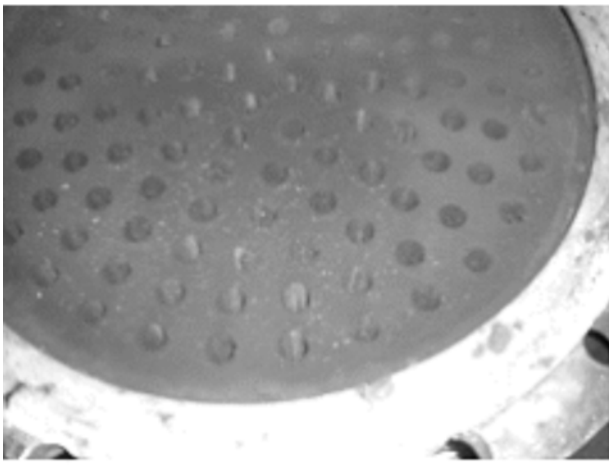
- The Korean anthracite and the waste plastic, used as fuel for the high-temperature air gasification system, were manufactured on a 50 : 50 basis. To understand the ignition temperature and com-

Table 2. Results of G/C analysis for Chinese anthracite gasification

	Air flow rate (Nm^3/hr)	Steam flow rate (kg/hr)	Gas composition (vol%)						Calorific value (kcal/Nm^3)
			CO_2	CO	H_2	CH_4	O_2	N_2	
No. 1	70	0	13.0	18.5	15.4	2.5	1.9	48.7	1,200
No. 2	60	0	12.2	19.3	14.4	2.3	1.4	50.4	1,176
No. 3	40	0	11.2	22.2	13.1	2.2	0.9	24.2	1,213
No. 4	30	0	10.5	22.4	12.8	2.1	1.3	50.9	1,201
No. 5	20	0	9.8	23.1	13.2	2.2	0.7	51.0	1,241
No. 6	50	7.2	11.9	20.7	17.4	1.6	1.4	47.0	1,240
No. 7	50	10	13.0	18.8	18.6	1.7	1.0	46.8	1,229
No. 8	50	15	14.6	16.5	20.6	1.5	1.3	45.6	1,203
No. 9	50	30	17.0	13.7	20.1	0.9	0.9	47.5	1,054



(a) Before running the reformer



(b) After running the reformer

Fig. 6. Comparison of tar and soot generation before and after running the high-temperature steam reformer.

bustion characteristics of the Korean anthracite, waste plastic and the mixtures of Korean anthracite and waste plastic, a certain amount of samples were burned at 15 °C/min ascending temperature gradient up to 1,200 °C while air was injected.

- For the initial operation in the fixed bed gasification experiment, Korean and Chinese anthracites were used in place of the mixtures of Korean anthracite and waste plastic.

- For the Korean anthracite, the syngas composition and heating value varied from 10 to 20% and from 300 to 800 kcal/Nm^3 as a function of steam and air flow rate. Therefore, it is concluded that Korean anthracite is hard to gasify because of low reactivity.

- Chinese anthracite has low ash content and higher heating value than domestic anthracite. The syngas composition was maintained about 20-40% and the calorific value was 800-1,300 kcal/Nm^3. We concluded that the gasification experiment performed stably.

- The large quantities of tar and soot generated in the gasification experiment are obstacles to long-term operations of the system. A reformer using high-temperature air/steam was installed just after the gasifier to combust and convert tar and soot into syngas. We confirmed the amount of generated tar and soot showed a salient difference after running the reformer.

- In the future, gasification experiments of manufactured mixtures of anthracite and plastic waste using 1.0T/D fixed bed gasifier will be performed.

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