Air gasification of dried sewage sludge and polyethylene using a new type three-stage gasifier: Effects of activated carbon used as tar removal additive and in-situ regeneration of activated carbon

Yong-Seong Jeong*, Bo-Sung Kang, and Joo-sik Kim

Department of Environmental Engineering, University of Seoul,
163 Siripdaero, Dongdaemun-Gu, Seoul 130-743, Republic of Korea

* Corresponding author: Tel: +822-6490-5479. Fax: +822-6490-5480. E-mail: jso4825@uos.ac.kr

Abstract

A new type three-stage gasifier consisting of an auger reactor, a fluidized bed reactor, a tar-cracking reactor was applied for the air gasification of dried sewage sludge (DSS) and polyethylene (PE) to obtain a high-quality producer gas with low levels of impurities (tar, NH, and H_2S). In the experiments, activated carbon (AC) turned out to be very effective in hydrogen production and tar removal. The maximum hydrogen concentration of producer gas obtained with activated carbon was approximately 29 vol%, and minimum tar content in producer gas was 142 mg/Nm^3 (DSS). The maximum hydrogen concentration of producer gas was about 27 vol%, and the producer gas was free of tar (PE). The in-situ regeneration of AC was conducted by stopping the feeding under gasification conditions. AC in-situ regenerated with air for 10 min with had a surface area of 937 m^2/g (83% recovery rate).

Keywords: In-situ regeneration; Three-stage gasification; Activated carbon; Hydrogen; Tar

1. Introduction

Gasification is one of the thermochemical conversion technology, which produces under oxygen-deficient conditions a combustible gas mixture containing H_2, CO, and CH_4, which is called producer gas or syn-gas. It is a promising environmentally benign technology, given that it is a flexible process that can operate with mixed plastics and even other wastes such as dried sewage sludge (DSS) and (waste) biomass. It, however, has seldom been implemented in industries, the main reason for which was a huge tar generation during gasification. The tar generated can cause blocking of pipelines of a gasification process and fouling of downstream equipment [1]. Hence, many approaches have been made to reduce the amount of tar, generally using additives, catalysts, and tar removing apparatus. Among those methods, the application of additives and cheap natural catalysts has been widely tested. Representative additives and catalysts were Ni-based catalysts, dolomite, olivine, etc.

Our research group has already developed a two-stage gasifier called the UOS two-stage gasifier and applied it along with AC as tar removal additive in the gasification of biomass and plastic to show a high tar removal efficiency of the process [2,3]. In the experiments, it was found that the main tar removal took place over AC, which is a widely used adsorbent due to its excellent adsorptivity and large surface area. However, it was in the works also observed that a progressive accumulation of coke was formed by reactions among tar molecules on the surface of AC to cause a decreased tar removal efficiency of AC.

Recently, we developed a new-type three-stage gasifier (The UOS three-stage gasifier), which consists of three serially connected reactors (auger, fluidized bed, and tar-cracking reactors). It has additionally an auger reactor in front of the UOS two-stage gasification process. In this study, the gasification of DSS and PE was performed in the UOS three-stage gasification process. This study mainly focused on in-situ regeneration of AC, which is crucial point to enhance the economy of the UOS gasification process. The in-situ regeneration was herein simply performed with air, the gasifying agent, under stopping feeding. In that situation, air was reacted with tar and coke on AC to remove them.

2. Experimental

2.1. Feed material and additives

DSS, which was supplied from an urban waste treatment plant equipped with anaerobic digestion and thermal drying units, and pellet-type of waste PE, which was supplied by a recycling company in Korea, were used as the feed materials in the study. The feed materials were first sieved to obtain materials with a size of 0.85−3.35 mm (DSS), 2−3.35 mm (PE). The main characteristics of the feed materials are shown in Table 1.

Table 1. Characteristics of feed material

DSS			
Proximate analysis (wt%)[a]		Ultimate analysis (wt%)	
Moisture	7.27 ± 0.01	Carbon	29.88 ± 0.86
Volatile matter	50.30 ± 0.02	Hydrogen	4.61 ± 0.08
Fixed carbon	7.73 ± 0.35	Nitrogen	4.34 ± 0.15
Ash	34.70 ± 0.32	Oxygen	25.41 ± 1.06
		Sulfur	1.06 ± 0.03
LHV (MJ/kg)	11.74		
PE			
Proximate analysis (wt%)		Ultimate analysis (wt%)	
Moisture	0.1 ± 0.01	Carbon	85.2 ± 0.16
Volatile matter	99.9 ± 0.01	Hydrogen	14.6 ± 0.07
Fixed carbon	N.D.	Nitrogen	N.D.
Ash	N.D.	Chlorine	0.2 ± 0.01
		Sulfur	N.D.
LHV (MJ/kg)	40.3		

[a] ASTM E871-82, ASTM E872-82, ASTM D1102-84.

Table 1 shows that the DSS contained high nitrogen (4.4 wt%) and sulfur (1.1 wt%) contents, which are precursors for NH_3 and H_2S generated during gasification. Proximate analysis of PE showed that it was mainly composed of volatile matter. Natural olivine was used as the bed material in the fluidized bed reactor, which had a diameter 150−300 mm. A coal-based virgin AC with a size of 1−2 mm was applied as a tar-cracking additive.

2.2. The UOS three-stage gasification process

A diagram of the three-stage gasification process is shown in Fig 1. The three reactors have their own roles in tar cracking. The auger reactor, at first, generates a huge amount of tar in advance of main gasification in the fluidized bed reactor. A small portion of tar can be destructed by oxidative thermal decomposition inside the auger reactor, and the tar leaving the auger reactor without being decomposed is cracked in the fluidized bed reactor thermally or by reactions with other gaseous components including oxygen. Finally, remaining tar after main gasification is removed in the tar-cracking reactor which is filled with AC as a tar-removal additive. After gasification in the three-stage gasification process, producer gas could be cleaned by a cyclone, hot filter, condensers and electrostatic precipitator.

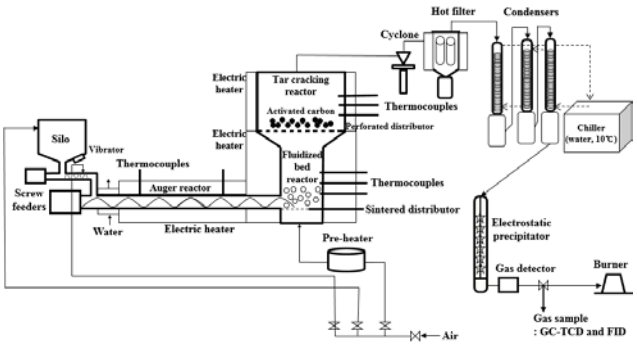

Fig 1. Diagram of three-stage gasification process.

2.3. Experimental conditions

Experimental conditions are summarized in Table 2. The fuel for Runs 1 (without AC) and 2 (with AC) were DSS, while Run 3−5 PE. Run 4 was examined to show the effect of AC on tar removal and hydrogen production. In Run 5, in-situ regeneration with air was performed for 10 min at the end of gasification run.

Table 2. Experimental conditions

Experimental conditions	Run1	Run2	Run3	Run4	Run5
Feed material	DSS	DSS	PE	PE	PE
Auger reactor temperature (°C)	645	659	503	495	502
Fluidized bed reactor temperature (°C)	807	811	828	823	820
Tar-cracking reactor temperature (°C)	814	820	811	820	820
Gasification time (min)	61	61	61	61	66
Equivalence ratio	0.35	0.34	0.30	0.30	0.32
Feed rate (g/min)	13.11	13.11	4.92	4.92	4.54
AC (g)	0	1600	0	1500	1500

2.4. Analysis of products

The producer gas, as the main product of the gasification process, was analyzed by means of GC-TCD for N_2, H_2, CO, CH_4, CO_2 and GC-FID for light hydrocarbons, with argon as the carrier gas. The types of columns used were Carboxen 1000 (TCD) and HP−plot Al_2O_3/KCl (FID). The contents of NH_3 and H_2S in producer gas were measured by a gas measurement analyzer (IR 9000, Rbr). The tar content in producer gas, which was defined as the sum of hydrocarbons with a molecular weight larger than that of benzene, was determined using a GC-FID. Additionally, the textural properties of the AC were measured using a BET analyzer.

3. Results and discussion

3.1. Effects of activated carbon

Comparison of Runs 1 and 2 (DSS) shows that the hydrogen in producer gas increased from 14.1 (without AC) to 28.5 vol% (with AC), and the tar content decreased from 2573 (without AC) to 142 mg/Nm^3 (with AC). Also AC decreased the tar content in the producer gas obtained with PE from 4528 (without AC) to 0 mg/Nm^3 and increased the hydrogen content from 6.6 to 26.8 vol%. The high tar removal efficiency of AC is largely due to their tar adsorptivity for its large specific surface areas, and the thermal or catalytic tar cracking on the surface of AC along with gaseous reactions such as water-gas reaction, Boudouard reaction. Because the NH_3 and H_2S contents in the producer gas of Run 1 (without AC) were over the upper detection limits, they also were strongly reduced by AC (Run 2).

3.2. In-situ regeneration

Compared to textural properties of the AC from Run 4 that was obtained without regeneration, the ACs after air regeneration turned out to have almost similar textural properties to those of the virgin AC: the BET surface area increased from 574 to 939 m^2/g, and the total pore volume also increased from 0.28 to 0.48 cm^3/g. The volume of micropores, which are defined pores less than 2 nm in width and provide active carbons with most of their surface area and adsorption characteristics [4], also increased after regeneration from 0.26 to 0.44 cm^3/g. Pore size distributions of ACs (Run 3−5) were shown in Fig 2.

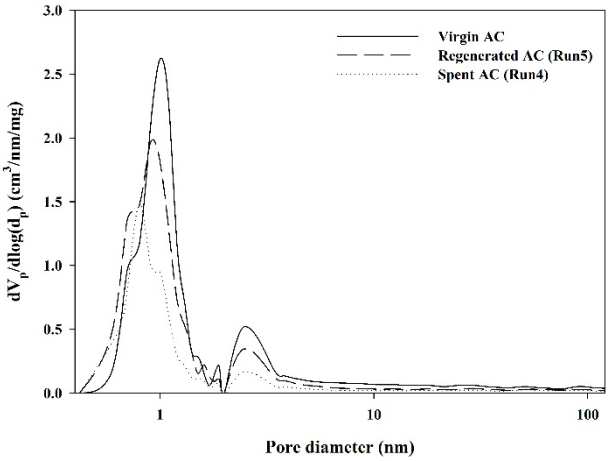

Fig 2. Pore size distributions of ACs

4. Conclusion

The new-type three-stage gasifier consisting of an auger reactor, a fluidized bed reactor, and a tar-cracking reactor in series was used for the gasification of DSS and PE. The auger reactor of the three-stage gasifier was expected to produce a large tar amount, which could be efficiently removed in subsequent reactors. The results of gasification of DSS and PE revealed that AC played important roles in impurities removal. However, it was gradually deactivated by cokes with increasing gasification time. To confront with the deactivation of AC, in-situ regeneration with air was conducted under stopping feeding. The regeneration was proved to be effective in short time operation. The micropore volume recovered from 0.26 (without regeneration) to 0.45 cm^3/g (with regeneration).

Acknowledgment

This work was supported by the New & Renewable Energy Core Technology Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea (No.20153030091340)

References

[1] Nakamura S., Kitano S., Yoshikawa K.: Biomass gasification process with the tar removal technologies utilizing bio-oil scrubber and char bed. Appl Energy. 170, 186−192 (2016)

[2] Mun T.Y., Kim J.S.: Air gasification of dried sewage sludge in a two-stage gasifier. Part 2: Calcined dolomite as a bed material and effect of moisture content of dried sewage sludge for the hydrogen production and tar removal. Int J Hydrogen Energy. 38, 5235−5242 (2013)

[3] Cho M.H., Mun T.Y., Choi Y.K., Kim J.S.: Two-stage air gasification of mixed plastic waste: Olivine as the bed material and effects of various additives and a nickel-plated distributor on the tar removal. Energy. 70, 128−134 (2014)

[4] San Miguel G., Lambert S.D., Graham N.J.D.: The regeneration of field spent granular-activated carbons. Water Res. 35, 2740−2748 (2001)