
Air gasification of mixed plastic wastes in a two-stage gasifier using olivine and activated carbon for the production of a low-tar and hydrogen-rich producer gas

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Abstract

In this work, air gasification was conducted with a fraction of mixed plastic wastes using a two-stage gasifier. For the production of a low-tar and hydrogen-rich producer gas, olivine as the fluidized-bed material and activated carbon as a tar-cracking additive were simultaneously used. When the amount of activated carbon increased from 0 to 1,500 g, the concentrations of H₂ and CO in the producer gas increased sharply from 9.3 to 31.1 vol% and from 3.2 to 8.6 vol%, respectively. When 1,500 g of activated carbon was applied, the total tar amount was about 97.5 % less than that obtained with only olivine as the bed material. The maximum Lower Heating Value (LHV) of the producer gas was about 8.2 MJ/Nm³.

Keywords: Mixed plastic wastes, Two-stage gasifier, Tar removal, Olivine, Activated carbon

1. Introduction

With the rapid population growth and increase of industrial activity, the worldwide production and consumption of plastics has increased. Recently, the research for the recycling of plastic wastes has been carried out to obtain environmental and economical benefits [1]. Among a variety of the different alternatives for plastic wastes treatment, gasification is one of thermo-chemical conversion processes, which converts waste plastics into a combustible producer gas, mainly made up of hydrogen, carbon monoxide and methane. In the gasification process, however, a huge amount of tar is released, which can cause operational troubles, for instance blocking joint pipe lines or fouling the process equipments [2]. In this study, a fraction of plastic wastes was gasified in a two-stage gasifier consisting of a bubbling fluidized bed (lower reactor) and a tar-cracking zone (upper reactor) in series using olivine as the fluidized bed material and activated carbon as the tar-cracking agent in the upper reactor.

2. Materials and Methods

Feed Material and additives. Pellet-type mixed plastic wastes used for this study were supplied by a recycling company, which consisted of various types of plastics such as polyethylene, polypropylene, polystyrene, polyvinyl chloride, polymethylmetacrylate (PMMA) and polyethylene terephthalate (PET). The proximate analysis of the mixed plastic fraction showed that its moisture, volatile matter, fixed carbon and ash content was 0.6 wt%, 94.2 wt%, 0.4 wt% and 4.6 wt%, respectively. In the element analysis, it was revealed that the feed material was comprised of 80.8 wt% of carbon, 12.8 wt% of hydrogen, 5.1 wt% of oxygen, 0.2 wt% of nitrogen and

1.1 wt% of chlorine. The bed material, applied in these experiments, was natural olivine. Olivine (2.5 kg) with a diameter of 150-300 μm was used as the fluidized bed material. The olivine was mainly composed of 44.2 wt% SiO₂, 8.0 wt% Fe₂O₃, 43.5 wt% MgO and other minor components, such as Al₂O₃ and CaO. Moreover, commercially available coal-based activated carbon pellets with a size of about 3.35-10 mm were applied in the upper reactor of the gasifier.

Gasifier and experimental procedure. The bench-scale gasification process consists of four main sections: feeding system, two-stage gasifier, char removal system and quenching system. The two-stage gasifier comprises a bubbling fluidized bed (lower reactor) and a fixed bed reactor (upper reactor) in series, made of a 310 SS tube, which was indirectly heated with electricity. The lower reactor has an inner diameter of 110 mm and a height of 390 mm, with four thermocouples. The upper reactor has an inner diameter of 160 mm and a height of 340 mm, with two thermocouples. The producer gas obtained in two-stage gasifier passed the char removal system composed of a high-efficiency cyclone and hot filter designed to capture particles larger than 100 and 10 μm, respectively. After char particles removal, condensable components in the producer gas were removed in the quenching system consisting of three steel condensers which operated with cool water at 10 °C. The aerosols and very fine particles after the quenching system were captured with an electrostatic precipitator. Some of non-condensable producer gas was sampled by means of teflon gas bags (1L) at intervals of 10 min to analyze its composition and the remaining gas stream was burned in a flare stack after its gas volume and temperature were measured. A diagram of the two-stage gasifier is shown in Fig. 1.

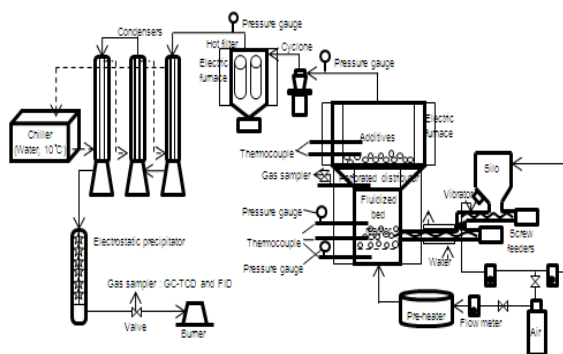


Fig. 1. A diagram of the two-stage gasifier

Reaction conditions. Gasification experiments (Runs 1 to 3) were conducted to investigate the influence of the amount of activated carbon on the composition of producer gas and the amount of tar produced. Run4 was conducted without EP, the results of which can be compared with those of Run3. Run5 was performed using an activated carbon filter instead of EP, the results of which can be compared with those of Runs 3 and 4.

Product analysis. After gas samples were taken from the exit of the gasifier, the gas samples were measured by means of gas chromatography (GCs) using a thermal conductivity detector (TCD) for N_2 , H_2 , CO , CH_4 , CO_2 and a flame ionization detector (FID) for light hydrocarbons. The tar contents in the producer gas were defined as organic molecules with a molecular weight larger than that of benzene, and it was quantitatively analyzed by using a GC-FID.

3. Results and Discussion

Table 1 shows compositions, tar contents and LHV of producer gases.

Table 1. Reaction conditions and producer gas compositions.

Parameter	Run1	Run2	Run3	Run4	Run5
Upper-reactor temperature (°C)	812	806	806	801	804
Lower-reactor temperature (°C)	831	833	823	814	826
Feed rate (g/min)	4.67	4.68	4.56	4.65	4.83
Operation time (min)	64	64	65	64	62
Equivalence Ratio	0.31	0.31	0.31	0.31	0.3
Activated carbon (g)	None	900	1500	1500	1500
Electrostatic precipitator	O	O	O	X	X(AF)
Composition (vol%)					
N_2	60.23	51.14	48.47	46.31	52.51
CO_2	13.04	8.56	7.76	8.46	4.61
H_2	9.34	27.09	30.25	31.05	30.63
CO	3.19	6.7	7.62	8.6	7.66
CH_4	9.1	6.39	5.88	5.57	4.59
C_2H_6	0.19	0.01	0.001	< 0.001	< 0.001
C_2H_4	3.37	0.05	0.002	0.001	< 0.001
C_2H_2	0.27	0.01	0.01	N.D.	N.D.
$C_3+C_4+C_5$	0.11	0.001	< 0.001	N.D.	N.D.
Benzene	1.09	0.05	0.002	0.004	N.D.
Toluene	0.04	0.001	< 0.001	< 0.001	N.D.
Tar in producer gas (mg/Nm ³)	2170	53	5	9	N.D.
Lower heating value (MJ/Nm ³)	8.22	5.81	6.03	6.05	5.56

O: applied, X: not applied, AF: Activated carbon filter

The increase in the amount of activated carbon led to a large increase in the concentrations of hydrogen (from 9.3 to 30.3 vol.%) and carbon monoxide (from 3.2 to 7.6

vol.%) in the producer gas. This is because tar cracking reactions were enhanced by activated carbon which could adsorb tars on its surface and therefore, prolong the residence of tars till they were cracked. When 1500 g of activated carbon was applied, the tar content in producer gas was sharply decreased to 5 mg/Nm³. Regarding the composition and tar content in the producer gas, there was no observable difference between Run 4 and Run 3, which showed the possibility of successful gasification operation without an EP. The comparison between Run 4 and Run 5 did not indicate a discrete difference on the composition of the producer gas and the amount of tar generated. In this study, the total amount of tar was defined as the sum of the tar collected in the condensers and tubes after quenching, the tar deposited on the apparatus and the tar captured by the electrostatic precipitator. Fig. 2 shows the total tar production and tar removal efficiency under various reaction conditions. As the amount of activated carbon increased (Runs 1 to 3), the amount of total tar decreased. When 1,500 g of activated carbon was applied (Runs 3 to 5), the tar removal efficiency reached up to 97.5 %.

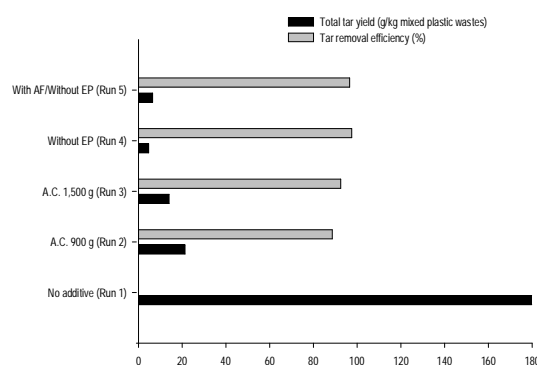


Fig. 2. Amount of total tar and tar removal efficiency

4. Conclusions

In this study, air gasification of a fraction of mixed plastic wastes was carried out to investigate the influence of operating conditions and additives on the composition of producer gas and the amount of tar. The maximum LHV of the producer gas was about 8.2 MJ/Nm³. When 1,500 g of activated carbon was applied, the concentration of hydrogen was 31.1 vol% and the total tar amount was about 97.5 % less than that obtained with only olivine as the bed material. To summarize, the producer gas generated in the experiments was considered suitable for the use as a fuel in internal combustion engines or fuel cells.

References

- [1] M.L. Mastellone, L. Zaccariello and U. Arena. Fuel 89 (2010) 2991-3000.
- [2] A. Paethanom, S. Nakahara, M. Kobayashi, P. Prawisudha and K. Yoshikawa. Fuel Processing Technology 104 (2012) 144-54.