HYDROGEN PRODUCTION FROM PYROLYSIS-GASIFICATION OF POLYPROPYLENE USING A SCREW KILN REACTOR SYSTEM

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Abstract

A screw kiln continuous reaction system was used and investigated for hydrogen production from the catalytic steam pyrolysis-gasification of polypropylene. A Ni-Mg-Al catalyst was investigated in relation to gasification temperature. The results showed that the introduction of the catalyst in the gasification bed dramatically improved the hydrogen production. For example, the potential H_2 production increased from only 2.53 wt.% (without catalyst) to 21.01 wt.% in the presence of the Ni-Mg-Al catalyst, when the pyrolysis temperature, gasification temperature and water injection rate was 500, 800 °C and 9.49 g h^{-1}, respectively. The gas and hydrogen production and amount of reacted water per hour were increased with the increase of the gasification temperature from 600 to 900 °C for the Ni-Mg-Al catalyst.

Keywords: *Polypropylene; Nickel; catalyst; Screw kiln*

1. Introduction

There is increasing interest in hydrogen energy due to its clean combustion and potential use in advanced technologies such as in fuel cells etc. [1,2]. The production of hydrogen from the thermal decomposition of plastics has been suggested to be a good alternative for waste plastics treatment and a possible way to produce extra hydrogen for a future energy system.

Among various reactors, the continuous screw kiln has been proposed to be a preferred reaction system for industrial commercialization [3]. The screw kiln reactor was suggested to have the potential to be used for the processing of waste plastics, which possess complex chemical and physical properties. Furthermore, the screw kiln reaction system might reduce the over-cracking of raw materials, and generate a comparatively narrow range of products that would be more easily reformed in a second stage to produce hydrogen gas.

In this paper, polypropylene was used as a raw material to be pyrolysed and gasified to generate hydrogen by combining screw kiln pyrolysis reactor with a fixed bed gasification reaction system. A laboratory prepared Ni-Mg-Al catalyst and a commercial Ni catalyst were investigated for the pyrolysis-steam catalytic gasification of polypropylene. The experimental parameters such as gasification temperature and water injection rate were also investigated.

2. Materials and Methods

2.1. Materials and catalyst.

Polypropylene (PP) was obtained as 2 mm virgin polymer pellets provided by BP Chemicals UK.

A laboratory-prepared Ni-Mg-Al catalyst was used in this work. Ni-Mg-Al catalysts were prepared using the rising pH technique according to the method reported by Garcia et al. [4] and our previous report [5].

2.2. Reaction system.

A schematic diagram of the screw kiln reactor is shown in Figure 1. The screw kiln reaction system mainly includes a materials feeding system, screw kiln pyrolysis system and the fixed-bed catalytic gasification system. The plastic materials were continuously fed into the pyrolysis reactor (62 mm diameter and 540 mm length), where a screw was placed through the reactor and was rotated by an electric motor. The plastics were screwed forward and pyrolysed in the screw kiln reactor. The screw kiln was heated by a small pre-heat furnace and a large main furnace. The derived pyrolysis gases passed through a fixed-bed vertical gasification reactor (25 mm diameter and 260 mm length) which was heated and controlled separately and also contained the catalyst bed. Steam was introduced into the gasification reaction system for the catalytic steam gasification of the product pyrolysis gases. The connection of the pyrolysis reactor with the gasification reactor was also heated by a small heater to avoid gas condensation before entering into the gasification bed. The generated gases were firstly condensed to collect any liquid condensable products and gases were then collected with a Tedlar™ gas sample bag, and analysed for gas concentration off-line using packed column gas chromatography.

The screw kiln rotation rate and polypropylene feeding rate was kept at 13.0 rpm and 11 g h^{-1}, respectively. The carrier gas (N_2) was introduced with a total flow rate about 200 ml min^{-1}. For comparative experiments in the absence of the catalyst, silica sand was used to represent base-line reaction conditions, to compare with the Ni-Mg-Al catalyst data.

The gaseous products collected in the Tedlar™ sample bag were analysed by packed column gas chromatography (Varian 3380) to determine the concentration of hydrocarbons and permanent gases.

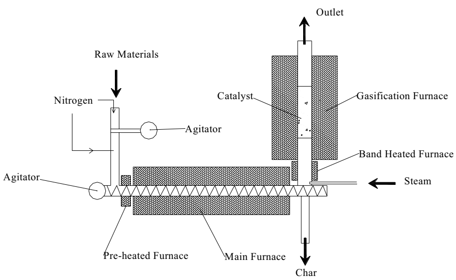

Fig.1. Schematic diagram of screw kiln reactor system

3. Results and Discussion

3.1. Influence of steam and catalyst on the gas and hydrogen production.

Experiments were carried out to investigate the influence of steam and catalyst on gas and hydrogen production from the pyrolysis-gasification of polypropylene. The pyrolysis temperature and gasification temperature were controlled at 500 and 800 °C, respectively. The gas production and hydrogen production results are presented in Table 1.

Table 1 Gas and hydrogen production

	Sand	Sand	Ni
Water injection rate (g h^{-1})	0	9.49	9.49
Reacted water (g h^{-1})	0	0.58	5.14
Gas production (g h^{-1})	0.75	2.35	9.08
H_2 production (g h^{-1})	0.03	0.12	0.99
Potential H_2 production (wt.%)	0.61	2.53	21.01

The results shown in Table 1 demonstrate that with the introduction of steam in the gasification process, gas production increased from 0.8 to 2.4 g h^{-1} and the H_2 production increased from 0.03 to 0.12 g h^{-1}. The presence of catalyst largely increases the gas and hydrogen production. In this paper, the potential H_2 production is presented corresponding to the maximum H_2 production. The maximum theoretical amount of H_2 produced from polypropyelene steam gasification is estimated to be 42.9 g per 100 g polypropylene. [5]

3.2. Influence of gasification temperature.

The gasification temperature has been investigated extensively during the pyrolysis/gasification process due to its importance. In this section, the gasification temperatures of 600, 700, 800 and 900 °C were studied with the continuous screw kiln reactor system. The water injection rate was controlled at 14.23 g h^{-1}. Pyrolysis temperature was kept at 500 °C.

The gas production and hydrogen production at different gasification temperatures with the Ni-Mg-Al catalyst are presented in Table 2. From Table 2, the reacted water was increased with the increase of gasification temperature for the Ni-Mg-Al catalyst. The hydrogen production rate and potential hydrogen production were also increased with increasing gasification temperature for both catalysts. In our previous work using a fixed bed reaction system, the potential H_2 production was found to be increased from 13.4 to 52.0 wt.% with a $Ni/CeO_2/Al_2O_3$ catalyst when the gasification temperature was increased from 600 to 900 °C [6]. In addition, a 57.1 wt.% potential hydrogen production was obtained in the presence of a Ni-Mg-Al catalyst at a gasification temperature of 800 °C using the two-stage fixed bed reaction system [6].

Table 2 Influence of gasification temperature

	600°C	700°C	800°C	900°C
Reacted water (g h^{-1})	3.69	8.78	9.73	12.59
Gas production (g h^{-1})	5.49	14.35	13.79	21.59
H_2 production (g h^{-1})	0.53	1.56	1.68	1.97
Potential H_2 production (wt.%)	11.27	33.01	35.58	41.65

4. Conclusions

In this paper, a screw kiln continuous reaction system was tested for hydrogen production from the pyrolysis-gasification of polypropylene. The process conditions such as gasification temperature and water injection rate were investigated with a Ni-Mg-Al catalyst. The results show that the amount of reacted water, gas production and H_2 production were increased with the increase of gasification temperature from 600 to 900 °C

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