Proceedings Paper:

Al-Rahbi, AS and Williams, PT orcid.org/0000-0003-0401-9326 (2017) Steam reforming of biomass tar over tyre char for hydrogen production. In: Correas, LC, Larrea, A, Lázaro, MJ and Peña, JA, (eds.) Special Issue on The 21st World Hydrogen Energy Conference (WHEC 2016), 13-16 June 2016, Zaragoza, Spain. 21st World Hydrogen Energy Conference, 13-16 Jun 2016, Zaragoza, Spain. , pp. 955-956.

Steam reforming of biomass tar over tyre char for hydrogen production

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Abstract

Carbonaceous materials have been proven to have a high activity for tar removal. The simultaneous gasification of pyrolysis gases and char has a significant role in increasing the gas yield and decreasing the tar in the product syngas. This study investigates the use of tyre char as a catalyst for hydrogen production and tar reduction during the pyrolysis/reforming of biomass using a two stage fixed bed reactor. The biomass sample was pyrolysed under nitrogen at a pyrolysis temperature of 500 °C. The evolved pyrolysis volatiles were passed to a second stage with steam and the gases were reformed at a temperature of 900 °C with the presence of tyre char as catalyst.

The influence of catalyst bed temperature, steam flow rate, reaction time and addition of metals were investigated. Char was characterized using BET surface analysis and scanning electron microscopy (SEM). Raising the steam injection rate and reforming temperature resulted in an increase in hydrogen production as steam reforming and gasification of char increased. Over the ranges of operating conditions examined, the maximum hydrogen content reached 52% and the ratio of H_2/CO varied between 1.3 to 2. The presence of steam promotes the char conversion, however, increasing the amount of steam from 6.64 g/h to 8.64 g/h doesn't contribute to decrease the char yield and the obtained hydrogen yield was almost the same at about 51 vol. %. The results indicate that the char bed exhibited a higher tar reduction than the thermal cracking conditions.

Materials and Methods

In steam reforming of biomass for hydrogen production, the experiments were carried out using a two stage reactor (Figure 1). The effectiveness of char for tar cracking was investigated using a fixed bed reactor by passing the product biomass pyrolysis vapours through a hot bed of char at 700, 800 and 900 °C . The experimental procedure consisted of the initial heating of the 2nd stage reactor, where the char is located, to the desired temperature at a heating rate of 40 °C min^{-1}. Once the temperature of the 2nd stage reactor was stable, the pyrolysis reactor was heated up at a rate of 40 °C min^{-1} to a final temperature of 500 °C. The liquid products including water and oil were allowed to condense using two dry ice condensers. The uncondensed gases were collected in a Tedlar™ gas sample bag for later off-line analysis. Further experiments were carried out to investigate the influence of tyre ash composition on tar reduction and hydrogen production during the pyrolysis-steam reforming of biomass. For this purpose, tyre char was treated with 5M HCl to remove the metals in the ash.

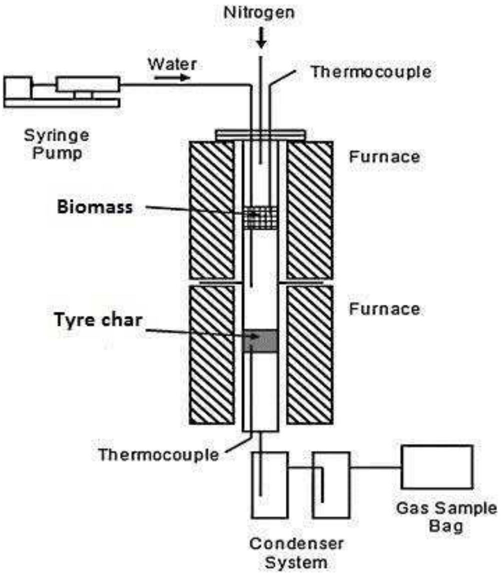

Figure1. Schematic two-stage pyrolysis-gasification reaction system

Results

The influence of temperature and steam addition was investigated in relation to the production of hydrogen. The gas yield and hydrogen production corresponding to the different water flow rates are presented in Table 1. Raising the water flow rate resulted in an increase in the hydrogen production to about 51.4 vol.%. The production of hydrogen in mmol per gram of biomass is shown in Table 1. 10.94 mmol/g of hydrogen was obtained for the pyrolysis/gasification of biomass with sand. The hydrogen production increased significantly with the use of tyre char in the 2nd stage to be about 39.20 mmol g^{-1} biomass due to tar cracking and char gasification reactions. Polycyclic aromatic hydrocarbons (PAHs) were found to present in a quite high concentration in the product tar at 900 °C with the use of sand, however the use of tyre char resulted in decomposition of the most of the tar compounds.

Tyre char treated with HCl was used to compare with the original tyre char on tar conversion and hydrogen production during the pyrolysis-steam reforming of biomass. As presented in Table 1, the removal of metals in ash resulted in a decrease in the hydrogen production to 30.4 mmol g^{-1} biomass at 900 °C. The difference in hydrogen production between the two types of char suggests that the metals in tyre char have a catalytic effect in enhancing the tar conversion.

Catalyst **Water flow rate (ml h^{-1})**	**Sand** **6.64**	**Tyre char** **3.64**	**Tyre char** **6.64**	**Tyre char** **8.64**	**Treated tyre char** **6.64**
Gas yield (wt.%)	14.31	94.82	131.55	130.28	106.74
Liquid yield (wt.%)	80.86	47.84	59.21	70.16	65.93
Mass balance (wt.%)	100.6	97.7	99.8	99.8	97.1
H_2 yield (mmol g^{-1} sample)	10.94	24.78	39.20	37.82	30.49
H_2: CO molar ratio	1.12	1.8	2.1	1.94	1.4
Gas composition (vol%)					
H_2	37.4	47.46	51.4	50.5	47.4
CO	33.4	26.35	24.4	26.0	33.5
CO_2	16.3	19.64	19.2	18.6	10.6
CH_4	9.1	5.51	3.8	4.1	6.7
C_2-C_4	3.3	1.03	1.1	0.9	1.75

Table 1. Influence of steam on the hydrogen production from the pyrolysis-catalytic gasification of biomass at 900 °C

Conclusions

The use of tyre char as a catalyst during the steam reforming of biomass promoted the production of synthesis gas (H_2 and CO). The results suggest that tyre char had a high efficiency in decomposing most of the tar compounds at a temperature of 900 °C.