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SYNGAS PRODUCTION FROM GREEN WASTE USING THE COMBINATION OF A ROTARY KILN WITH A TUBULAR REACTOR

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1. Keywords

Green waste, pyrogasification, thermal cracking, steam reforming, rotary kiln, tubular reactor

2. Highlights

- Effectiveness of a two-stage system (a rotary kiln with a tubular reactor) for nitrogen and tar free syngas production
- High gas and hydrogen yields.

3. Purpose

There is a growing interest in the application of thermochemical processes such as pyrolysis and gasification for renewable fuels production. Whereas pyrolysis can be optimized to obtain bio-oil and char, gasification is more favourable to syngas (CO, H₂ and CO₂) production. The produced syngas can be converted into fuels like methane, gasoline and diesels. The upgrading processes require a high H₂/CO molar ratio as well as the lowest possible tar and pollutants concentrations. Therefore, tar removal and gaseous products yield increase from biomass gasification are serious challenges. Two stage combined pyrolysis-gasification has been found to be effective for thermochemical biomass conversion producing enhanced gas yield, low tar content and high biomass conversion rates [1]. In this work, a two-stage pyrolysis-gasification process is used to produce a high-quality syngas suitable for biological methanation. Pyrolysis is performed in a rotary kiln and volatiles non-catalytic reforming is carried out in a tubular reactor.

4. Materials and methods

Green waste and wood pellets (6 mm diameter) are the biomasses considered in this work. Green waste consists of garden waste which contains mostly small branches. It does not include leaf nor grass. Pyrolysis - steam reforming experiments were carried out in two separate reactors. Pyrolysis experiments were performed in a 4.2 m long pilot-scale rotary kiln with a 0.21 m inner diameter. All experiments were performed with a 3° inclination of the rotary kiln tube, a rotation speed of 3 rpm and a 45' mean solid residence time. Steam-reforming was carried out in a 1.65 m long entrained flow reactor with a 75 mm inner diameter. In all experiments, 6 kg/h of biomass were fed into the rotary kiln preheated at 800°C for pyrolysis. When the steady-state was reached (about 2h), char was collected at the reactor outlet. Part of the produced volatile matter (300 or 600 l/h) was transferred to the tubular reactor through 400°C heated pipes to be reformed at 1200°C and 1300°C. The gas and bio-oil were sampled and analysed with μ -GC and GC/MS respectively.

5. Results and discussion

Table 1 summarizes mass balance as well as gas and tar composition for the selected test conditions. Biomass pyrolysis in the rotary kiln produces 80 wt.% volatile matter and 20 wt.% char (dry basis). Gas composition is dominated by CO (7.1 mmol/g biomass db) and H₂ (6.6mmol/g biomass db). Tar qualitative and quantitative analysis by GC/MS show the predominance of benzene and naphthalene. Although the gas yield increases with steam reforming, a residence time fixed to 5s and a

temperature increase from 1200 to 1300°C increase the gas yield by 0.97%. In contrast, at 1300°C, increasing the residence time from 5 to 10 s decreases the gas yield by 3%. As the temperature increases from 1200 to 1300°C, the tar yield decreases by 54%. Furthermore, 99% of the tar produced at 1300°C disappears when the residence time is two time longer. However, the soot yield does not seem to vary with temperature. On the other hand, it increases by 3% when the residence time increases from 5 to 10 s at 1300°C. It is evident from these results that the temperature increase promotes tar thermal cracking and increases the gas yield, especially hydrogen even if the reverse water gas shift reaction is favoured at these temperatures. The H₂/CO ratio remains almost constant (about 1.4). However, the time residence increase may favour the tar reduction but also soot formation. Benzene and naphthalene decrease as a function of temperature and residence time. These findings are in total agreement with studies on thermal conversion of tars [2].

Table 1: Summary of global balance and components concentration during reforming. All data is referred to biomass dry basis.

Species	Pyrolysis 800°C	Steam reforming 1200°C	Steam reforming 1300°C	Steam reforming 1300°C
Mean residence time (s)	-	5	5	10
Mass balance (wt.%db)				
Gas/biomass	48.64	56.68	57.24	54.07
Char/biomass	19.42	-	-	-
Tar/biomass	11.53	5.37	2.48	0.01
Water/biomass	20.41	8.92	11.74	15.38
Soot /biomass	-	9.61	9.12	11.11
Gas analysis (mmol/g biomass db)				
H ₂	6.58	17.70	20.42	19.74
CO	7.11	12.54	14.52	13.99
CO ₂	4.05	3.39	2.62	2.34
CH ₄	4.13	1.54	0.54	0.34
C ₂ -C ₃	1.05	0.23	0.04	0.01
Bio-oil analysis (wt.%db)				
Benzene	2.66	0.00	0.00	0.00
Naphthalene	0.72	1.32	0.84	0.01

6. Conclusions and perspectives

The present work demonstrates the feasibility of producing N₂ and tar free syngas with a two-stage reactor system. As expected, the product yield from volatile matter steam reforming depends mainly on the final temperature level and the residence time. It is necessary to manage the process operating system to reduce the soot formation and increase hydrogen concentration. Soot formation should be avoided because it reduces carbon conversion yield and impacts the economical balance of the whole process. Future works will be focused on studying soot formation mechanisms and potential methods to avoid it such as the use of low cost catalysts (based on char and ash).

7. References

- [1] Waheed, Q. M. K. & Williams, P. T. Hydrogen Production from High Temperature Pyrolysis/Steam Reforming of Waste Biomass: Rice Husk, Sugar Cane Bagasse, and Wheat Straw. *Energy & Fuels* **27**, 6695–6704 (2013).
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