GASIFICATION OF RESIDUAL BIOMASS IN A ROTARY KILN REACTOR INTEGRATED WITH RADIO FREQUENCY PLASMA TORCH

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Significance and Relevance

Process intensification of biomass gasification is of paramount importance to improve the producer gas quality, pushing towards a higher production of hydrogen. Low hydrogen content and the presence of tar are the main challenges to be addressed. At this regard, for the first time, a rotary kiln gasifier is integrated with a radio frequency plasma torch. The proposed integration significantly improves both the hydrogen yield and the H_2-to-CO ratio, with no gravimetric tar.

Introduction and Motivations

Biomass conversion towards chemical intermediates or fuels is considered as one of the most important decarbonization strategy[1]. At this regard, the research and development activities carried out on biomass gasification are focused, from a technological point of view, on the tar reduction as well on the increase of hydrogen production. Tar as well as low hydrogen content is recognized as the "Achilles heel" of the gasification. To date very limited literature was recovered about biomass gasification in rotary kiln[2,3]. The aim of this work is to demonstrate the suitability of the integration of rotary kiln with a plasma torch device, able to produce a clean syngas with high hydrogen content, also under not optimal conditions for air gasification, i.e. 650 °C and an equivalence ratio equals to 0.15.

Materials and Methods

Residual lignocellulosic biomass is used as feedstock for a gasification process carried out with air as gasifying agent. A 10 kW_{th}-rotary kiln was used as gasifier. The effect of gasification temperature on the producer gas quality was studied in the range 650-900 °C. The biomass is fed with a flowrate set at 190 g/h, 450 g/h or 900 g/h. Post-gasification treatment was assessed by considering both conventional thermal unit (up to 1100 °C) and plasma-based unit adopting a radio frequency plasma torch.

Results and Discussion

On the basis of nitrogen-free composition, the trends indicate that both hydrogen and carbon monoxide content increase as the gasification temperature increases, while an opposite trend is observed for carbon dioxide and methane. Higher temperature favors endothermic reactions such as Boudouard, reverse water gas shift, reforming (steam/dry) and cracking of hydrocarbons, while exothermic reactions, such as methanation is hindered. Due to an increase of endothermic reactions both hydrogen and carbon monoxide concentration increase. Endothermic reactions, such as Boudouard and reverse water gas shift and dry reforming occur with carbon dioxide consumption that can be the cause of decrease of carbon dioxide concentration in the syngas by increasing the gasification temperature. The beneficial effect of gasification temperature on both syngas yield and syngas lower heating value has a direct effect on cold gas efficiency, that proportionally increases from about 20% to about 64% in the investigated temperature range, as reported in Figure 1.

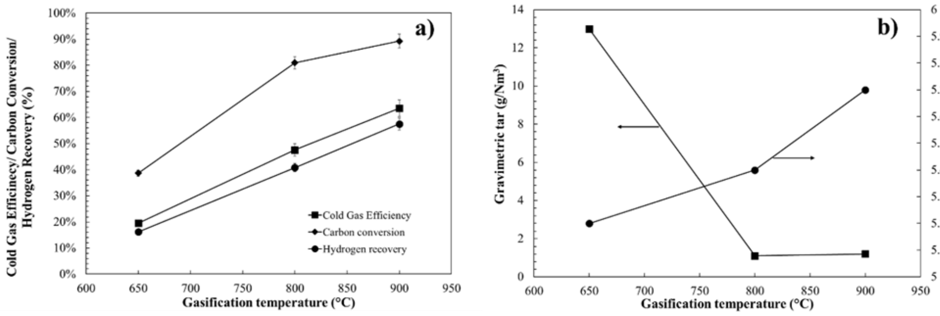

Figure 1 – Effect of gasification temperature on gasification performances

As a rule, the increase of biomass reactivity pushed by temperature increase favor the conversion of carbon and hydrogen, from solid phase to gas phase. In fact, carbon conversion increases from about 39% to about 89% by increasing the temperature from 650°C to 900°C. Hydrogen recovery linearly depends on the temperature, under the investigated conditions.

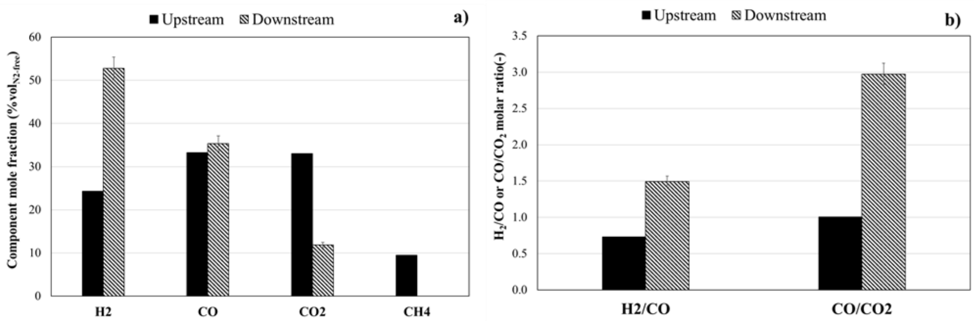

Figure 2 – Syngas composition (a) and H_2/CO and CO/CO molar ratio (b) upstream and downstream radio frequency plasma torch during the following gasification tests: 450 g/h, 650°C, e.r. 0.15

Figure 2-a shows the effect of post-gasification treatment on syngas composition calculated on nitrogen-free basis. It is noteworthy the strongly reduction of methane in the syngas, whose downstream radiofrequency plasma torch concentration is lower than the limit of detection. The elimination of methane from syngas can be caused by several reactions that are favored at high temperature, such as steam and dry reforming, as well as thermal cracking.

Furthermore, radiofrequency plasma torch treatment causes an undoubtedly increase of both hydrogen and carbon monoxide concentration, with a parallel decrease of carbon dioxide concentration. These changes as an effect in terms of both H_2-to-CO and CO-to-CO_2 molar ratio, as depicted in Figure 2-b. The ratio between the generated hydrogen and the generated carbon monoxide is higher than one, i.e. about 2.3, indicating that steam reforming of hydrocarbons could be the predominant reaction. Since a carbon dioxide flowrate reduction was observed, dry reforming and/or reverse water gas shift probably occur in the system

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