Small-scale producer gas upgrading: hydrogen yield enhancement over a char bed reactor

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To support various applications where full electrical systems are ineffective or impractical, a successful decarbonized energy system will require a significant percentage of renewable liquid and gaseous fuels. Biomass gasification has been highlighted as one of the most promising thermochemical processes for converting lignocellulosic feedstocks to a versatile synthetic gas that can be further processed into a range of fuels and chemicals (Ptasinski 2016). However, biomass gasification faces a number of technical challenges that limit its efficiency and viability in comparison to hydrogen and biofuels provision (Sikarwar et al. 2017; Cao et al. 2020), including a lack of reducing equivalents available in the form of hydrogen, which are required for the synthesis of high energy density drop-in fuels. Low hydrogen concentration is particularly problematic in gasification systems that rely on partial internal combustion to meet the gasifier's enthalpy needs, such as air gasification.

The objectives of the present study were to test the operation of a producer gas reforming unit under a range of temperatures and steam-to-syngas ratios and for each evaluate: 1) the relative increase in hydrogen concentration and yield in comparison to standalone air gasification, 2) the achievable rates of char carbon conversion, and 3) the compatibility of the obtained syngas compositions with the stoichiometric ratios required in the synthesis of several biofuel types. A comprehensive set of experiments were carried out with a small pilot-scale open top air gasifier (OTG, Φ_{int} = 13 cm) operated with biomass pellets and coupled to a producer gas allothermal reforming reactor (GRF, Φ_{int} = 14 cm) filled with char produced in the OTG, heated with an electrical split-furnace and fed with a steam generator (Figure 1).

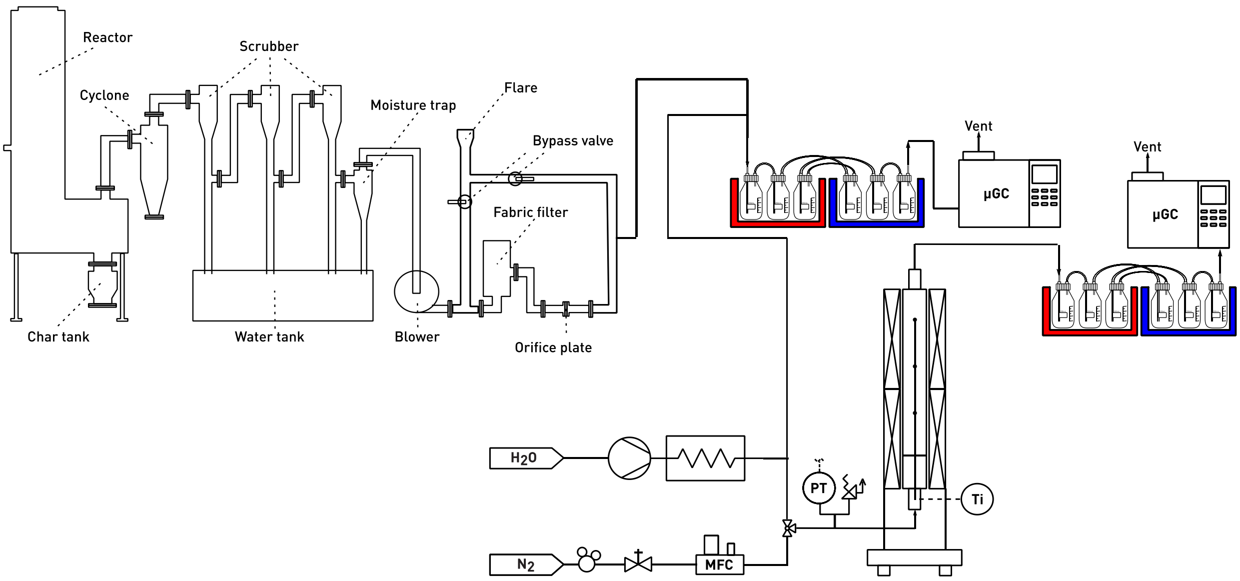

Figure 1. Setup layout (MFC = Mass Flow Controller, PT = Pressure Transducer, Ti = Internal Thermocouples).

The experiments were conducted at temperatures of 700 °C, 750 °C, 800 °C, and 850 °C and the reactor was operated at different steam flow rates and residence times. Table 1 reports the list of the experiments with the corresponding nomenclature; the GRF was firstly tested without char and steam (cases 0) and without flowing the producer gas, but with char and steam (cases I) – these latter cases to test the effect of steam injection on hot char without producer gas, reproducing the experiments already performed by the authors with a different system and reported in a previous work (Piazzi et al. 2021). Then, flowing the producer gas, the GRF was tested without char but with steam (cases II), with char but without steam (cases III), and with both char and steam (cases IV). At the temperature of 750 °C, the effect of residence time was also investigated, by changing the char bed height (CH600 and CH1200 for char bed initial mass of 0.6 kg and 1.2 kg, respectively).

Table 1. Details of the performed experiments – T = Temperature, ST = Steam flow, (X) = Number of RPM of the peristaltic pump of the steam generator, CH = Char bed mass in grams, PG = Producer gas.

Cases	**0**	**I**	**II**	**III**	**IV**
p.gas	✓	✗	✓	✓	✓
char	✗	✓	✗	✓	✓
steam	✗	✓	✓	✗	✓
T (°C)					
700	T700-PG	T700-ST(X)-CH1200-PG0	T700-ST(X)-CH0-PG	T700-ST0-CH1200-PG	T700-ST(X)-CH1200-PG
750	-	-	T750-ST(X)-CH0-PG	T750-ST0-CH600-PG	T750-ST(X)-CH1200-PG T750-ST(X)-CH600-PG
800	T800-PG	T800-ST(X)-CH1200-PG0	T800-ST(X)-CH0-PG	T800-ST0-CH1200-PG	T800-ST(X)-CH1200-PG
850	-	-	-	-	T850-ST(X)-CH1200-PG

The producer gas composition exiting the OTG was in average (vol.% wet basis) H_2 16.0 % , CO 17.7 %, CO_2 14.5 %, CH_4 2.9 %, N_2 46.0 %, H_2O 2.9 %, with an average char yield of 0.10 $kg_{char}/kg_{biomass}$, and a hydrogen yield of 18.1 $g_{H2}/kg_{biomass}$. The reaction of the producer gas CO_2 with the carbon available in the char bed (Boudouard reaction) increased the CO fraction, which, in turn, reacted with steam to increase the hydrogen content, through the Water-Gas-Shift reaction (WGS). This reactions pathway was favored or not depending on the operating conditions. The results of the experiments showed that an increase in hydrogen concentration occurs while increasing the temperature and the steam flow rate. Figure 2 reports the syngas composition variations in some specific cases. The highest values obtained at similar residence time and steam flow were (vol.% wet basis) 36.6 %, 38.6 %, 45.6 % and 47.0 %, at 700 °C, 750 °C, 800 °C, and 850 °C, respectively. However, the hydrogen yields did not follow the same trends, due to the decreasing rate of the WGS at higher temperature, which is opposite to the Boudouard reaction. As a matter of fact, the highest H_2 yield of approx. 50 $g_{H2}/kg_{biomass}$ was achieved at 750 °C, which represents the optimum temperature among the investigated ones in terms of hydrogen production. This work indicates an alternative option to produce hydrogen-rich syngas from air gasification.

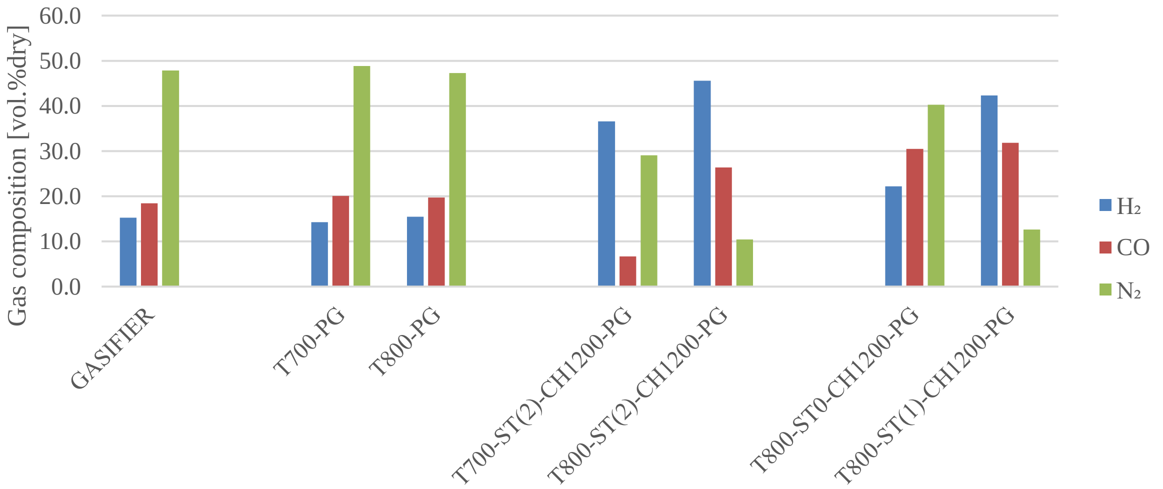

Figure 2. Producer gas composition.

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