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Influence of the main gasifier parameters on a real system for hydrogen production from biomass

M. Moneti ^{a,*}, A. Di Carlo ^b, E. Bocci ^c, P.U. Foscolo ^b, M. Villarini ^a,
M. Carlini ^a

^a Tuscia University, Via S. M. in Gradi 4, Viterbo, Italy

^b University of L'Aquila, Piazzale Pontieri, L'Aquila, Italy

^c Marconi University, Via Plinio 24, Rome, Italy

ARTICLE INFO

Article history:

Received 30 November 2015

Received in revised form

17 May 2016

Accepted 18 May 2016

Available online 10 June 2016

Keywords:

Biomass

Hydrogen

Gasification

Catalytic filter

ABSTRACT

The production of hydrogen from waste biomass could play an important role in the world energy scenario if efficient and reliable processes will be developed. Via kinetic and thermodynamic simulation and experimental data system, realized during the European project UNIfHY, to produce pure hydrogen from biomass is analysed. The plant is mainly composed of bubbling fluidized bed gasifier with catalytic filter candles, Water Gas Shift and Pressure Swing Adsorption (PSA). Focussing on the hydrogen production, a sensitivity study was carried out varying parameters as the steam to biomass ratio and the gasifier operating temperature. The results show that the hydrogen yield increases at increasing temperature and steam to biomass ratio, even if the required energy input increases as well. The global efficiency depends substantially on the PSA unit: the off gas of this unit is composed of residual CO, CH₄ and H₂, that can be burned in the combustor of the dual fluidized bed gasifier to supply the extra-heat to the gasification process avoiding the input of auxiliary fuel.

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Introduction

The development of reliable, efficient and low cost renewable energy power plants is a possible solution of the today environmental, social and economic issues [1]. Among renewables biomass can represent a useful alternative [2–4]. Hydrogen, as energy vector, is one of the most promising options because it, differently from electricity, can cover all the energy needs (e.g. storage, extra gravitational propulsion); furthermore it is “clean” and it allows a distributed production from local resources [5–8]. However it is still produced especially from

fossil fuels (Fig. 1) [9], in particular by natural gas steam reforming.

The Steam Methane Reforming (SMR) is a catalytic process that involves a reaction between natural gas or other light hydrocarbons and steam. In a conventional SMR methane reacts with steam to form hydrogen and carbon monoxide. The reaction is typically carried out at temperature of 800–1000 °C and a pressure of 14–20 bar. The effluent gas from the reformer contains about 76% H₂ (mol%), 13% CH₄, 12% CO and 10% CO₂ on a dry basis [10].

Among hydrogen production technologies using renewable sources, water electrolysis is a well-established process.

* Corresponding author. Tel.: +390761357416.

E-mail address: marta.moneti@unitus.it (M. Moneti).

<http://dx.doi.org/10.1016/j.ijhydene.2016.05.171>

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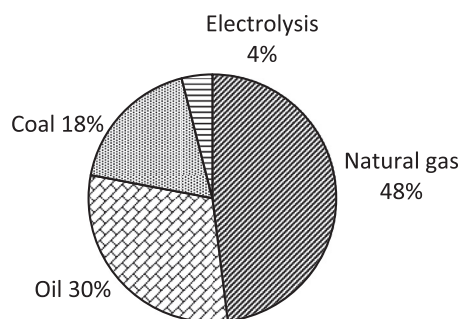


Fig. 1 – Energy sources utilized traditionally to produce hydrogen.

The main drawback is the high cost of the electricity consumed, which represents about 80% of the hydrogen cost [11–13]. An alternative, more economic process is waste biomass gasification to produce pure hydrogen [14–16]. In particular, small scale applications are very interesting because they follow the low energy density and perishability of this fuel exploiting the biomass directly *in loco* avoiding disposal costs, but efficient and reliable systems have still to be developed.

Biomass gasification is a thermo-chemical conversion process, which utilizes oxidizing agents (air, oxygen, steam or a mix of them), to produce a fuel gas (syngas) rich in hydrogen, carbon monoxide, methane; carbon dioxide, steam and nitrogen, in addition organic (tar) and inorganic (H_2S , HCl , NH_3 , alkali metals) impurities and particulate are also obtained [17]. Conventional small-to-medium scale gasification technologies utilize fixed bed reactors and air as gasification medium. This results in low conversion efficiency and in a syngas with a poor hydrogen fraction, because nitrogen contained in the air dilutes the syngas and its purification requires higher energy consumption. A possible solution to reduce the amount of N_2 in the product gas is biomass gasification with oxygen and steam [18]. Nevertheless, cost of oxygen –today especially used in coal gasification [19] – is still too high for a feasible application in small scale plants [20–23]. A steam blown indirect heated biomass gasifier, as the one analysed in this work, avoids problems caused by air producing a gas with high calorific value (12–14 MJ/Nm³) and high content of hydrogen [22,23], although the plant complexity increases owing to the additional combustor and the additional heat recirculation system between combustor and gasifier. Since particulate, organic and inorganic impurities are undesirable and noxious by-products, gasification is followed by gas cleaning processes as filtration, scrubbing, reforming, cracking, etc. [24–26]. Filtration and scrubbing at low temperature are at the moment the most used technologies. They remove particulate, TAR and nitrogen compounds. The disadvantage of these technologies is the gas cooling and the production of waste to be treated. Furthermore, in order to increase the hydrogen content, carbon monoxide and methane in the gas have to be converted by high temperature processes as reforming. As a consequence the further hydrogen purification steps would have low thermal efficiency because additional energy sources or extremely complex heat recovery would be necessary to re-heat syngas for the subsequent gas upgrading [27,28]. Hot

gas cleaning and conditioning methods, as the one here analysed, offer several advantages, such as thermal integration with gasification reactor, high tar conversion and hydrogen rich syngas production. The use of calcined dolomite, limestone and magnetite have been found able to increase the gas hydrogen content [29] even if they are not sufficient to produce a nearly tar-free syngas ($<0.5 \text{ g/Nm}^3$) [30]. Catalytic filters have been proposed as an alternative to be coupled to biomass gasification processes [31,32] and can be integrated directly in the freeboard of the fluidized bed reactor, as in UNIQUE concept [33]. Such configuration produces a syngas similar to that obtainable by SMR, almost free of tar and sulphur compounds, allowing a remarkable plant simplification and reduction of costs [33–35], but containing less hydrogen. In order to further increase the hydrogen content a WGS intermediate step is required. Several works [31,32,34,36] showed that the use of catalytic filter candles inserted directly in the freeboard of the fluidized bed gasifier can reduce total tar to values far below 1 g/Nm^3 , and that residual tars are mainly light tars (toluene and naphthalene in less quantity). In parallel, as demonstrated in the work of Stemmler et al. [37], high temperature sorbent (Ba based) can be used directly in the bed or downstream the reactor to reduce the concentration of H_2S and HCl concentration to values below 1 ppmv.

Today, the industrial implementation of WGS takes place usually in a series of adiabatic converters where the effluent is converted in two steps with the second one at a significant lower temperature in order to shift the equilibrium towards the hydrogen product. Conventional WGS reactors are used for large scale application and operate at high pressure and thus they are not suitable to be coupled with atmospheric pressure gasification (suitable for small scale applications).

During the UNifHY project [38], a WGS reactor operating at atmospheric pressure has been assembled with catalysts impregnated and supported on ceramic foams, to keep the efficiency of the gas–solid (i.e. the catalytic surface area) contact and reduce the pressure drop. The hydrogen rich gas at the outlet of WGS reactor (WGSR) is cooled down and then compressed to feed a PSA unit, which operates at relatively low pressure, to separate H_2 from residual gases producing hydrogen PEMFC (Proton Exchange membrane Fuel Cell or PEMFC) grade. The WGSR (as described above), the compressor and PSA are all part of the Portable Purification System (PPS) realized by the partner Hygear in the ambit of the UNifHY project (HYGEAR B.V. “Engineering for sustainable growth”).

Following the plant and the gasifier model description, this work shows the results of the system simulations carried out to analyse the influence on the hydrogen conversion efficiency of the variation of the main gasifier parameters (steam to biomass ratio and gasification temperature).

Plant description

The simplified ChemCAD[®] flowchart used for simulations is shown in Fig. 2.

Biomass (stream 1) is fed into the gasification zone (Gasifier) and gasified with steam (stream 2). The bed material, together with some charcoal (stream 3), circulates to the combustion zone (Burner). The particulate solid in this zone is

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