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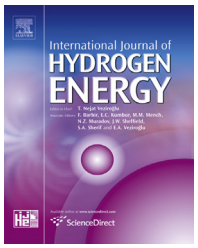

Syngas production from residual biomass of forestry and cereal plantations using hybrid filtration combustion

Sebastián Caro, Daniel Torres, Mario Toledo *

Department of Mechanical Engineering, Universidad Técnica Federico Santa María, Av. España 1680, Valparaiso, Chile

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ABSTRACT

This work shows and discusses the experimental results obtained from hybrid filtration combustion using biomass pellets originating from cereal plantations and forestry industry, which are some of the most common residual biomass sources in Chile. The biomass is made from oat cane, wheat cane, shining gum (Eucalyptus nitens) and insignis pine (Pinus radiata). The experiments were carried out using a porous media reactor filled with biomass pellets and alumina spheres in equal volumetric quantity. The gasifying agents used were a natural gas–air mixture (equivalence ratio: $\Phi = 1.1$) and an air-steam flow, in which the steam content varied from 20 to 40% of the initial air flow, changing filtration velocity from 26.1 to 31.3 and 36.5 cm/s, respectively. Using natural gas, temperature increased only using insignis pine while the usage of cereal plantation residuals enhanced syngas production. Maximum syngas production was achieved using wheat cane, obtaining 50% more H_2 and 97% more CO than the base line. Using steam, temperature of combustion was slightly influenced by a steam presence increase. Also, H_2 production was only enhanced when using wheat cane and insignis pine, while CO production was lower than the base line in every case. Maximum H_2 and CO production were obtained by the base line of shining gum, showing that the presence of steam disfavors syngas production in most cases.

Introduction

Nowadays, the importance of developing clean fuels has been increasing due to strict environmental standards on emissions that affect the use of common hydrocarbon fuels. In this context, hydrogen has been gaining attention by being considered as the energy carrier of the future [1]; its high energy content per mass [2], clean combustion (with air it only generates water steam and nitrogen oxides) and since it is not available in nature; new, innovative and economic techniques to produce it are strongly necessary. Moreover, hydrogen is a high value chemical, widely used in chemical and petrochemical industries in several processes such as the

* *Corresponding author.*
E-mail address: mario.toledo@usm.cl (M. Toledo).
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Fischer–Tropsch, ammonia production or Hydrocraking. Attractive applications of hydrogen's use for high efficiency electricity production via fuel cells are being studied, projecting it even as an alternative to transportation fuels, internal combustion engines and electric/hybrid vehicles in the automobile industry [3–5]. However, some difficulties still affect the use of hydrogen as a massive consumption fuel; among the most important are production, storage, distribution, safety and public perception [6].

Hydrogen can be produced from several processes and sources. Reforming of hydrocarbons, specially steam reforming of methane, is the leading process for hydrogen industrial production [7]. Partial oxidation, catalytic partial oxidation of gaseous and liquid hydrocarbons, electrolysis, and photolysis among other technologies are available for hydrogen production, which are less economically feasible. Nevertheless, these processes produce carbon dioxide as a by-product [8], require high energy supply, high pressure or the presence of expensive catalysts.

On the other hand, biomass provides 10% of the primary energy resources in the world [9]. Gasification of biomass is able to produce hydrogen and its use is considered environmentally friendly due to the use of fuels coming from natural carbon dioxide consumers, assented as CO_2 neutral and having very low sulfur content [10].

Hybrid filtration combustion introduces a process that combines the properties of filtration combustion in inert porous media, which consists on exothermal waves of reactions that propagate in a porous medium -that has been well described and studied [11–17]- and solid fuels gasification, allowing the usage of renewable energy solid fuels, by replacing a fraction of the inert solid's volume for a solid fuel. Experimental hybrid filtration combustion has been studied for syngas production using carbon [18], coal [19], wood pellets [20] and polyethylene [21] among other solid fuels and a mathematical model based on mass and energy equilibrium equations has been proposed [22,23]. Salgansky et al. [19] studied and modeled [22] the filtration combustion of a steam–air flow in a porous media composed on carbon and an inert solid material; temperature in the combustion wave and product composition are obtained varying the carbon fraction (from 10 to 100%) and steam (varying water/oxygen from 1 to 4.5) present in the oxidant. The maximum combustion wave temperature showed a slight dependence on the porous bed composition and steam presence. An increase in steam presence in the oxidant lead to a rise in hydrogen concentration in the gaseous products and caused a decrease in carbon monoxide concentration. Coal experiments were done using a rich natural gas–air mixture and varying the porous bed composition from 0 to 75% of coal pellets; it was observed that hydrogen yields and flame temperatures increased by augmenting filtration velocity and that flame temperatures decreased with an increase of the coal fraction of the porous bed; maximum hydrogen conversion was achieved with 75% of coal content in the porous bed [19]. For wood pellets (50% alumina spheres, 50% wood pellets in volume), rich and ultra-rich combustion of butane experiments, hydrogen and carbon monoxide are the dominant products and compared with the inert porous media partial oxidation of butane, a higher presence of syngas in the products is reported [20], showing that wood presence boosts syngas production. Recent research has shown that syngas can be produced using wood pellets in a lean mixture of natural gas–air filtrational combustion [24], varying Φ from 0.3 to 1, obtaining the maximum hydrogen conversion (~99%, related to the filtered mixture) at $\Phi = 0.3$.

Studies regarding biomass gasification, such as the results reported by Gao et al. [25], show the effects of gasifier temperature, Φ and steam to biomass ratio on a fixed bed gasifier with pine sawdust also considering producer gas reforming on a porous ceramic. In this case, results show that syngas was produced with air as a gasifying agent and that by increasing Φ in lean conditions (from 0 to 0.30), H_2 concentration decreased (from 44.45 to 23.56%) while CO first increased and then decreased with values between 20 and 25%. In the steam to biomass ratio range studied (1.05–3.47) was found an optimal point at 2.05. Although these yields and results are high, the work states that this is due to the reforming section included. Yang et al. [26] used a fixed-bed batch reactor to perform a high-temperature gasification of wood pellets over an alumina spheres bed and air as the gasifying agent. In addition, the process is numerically studied. In this case the maximum measured concentrations of CO and H_2 were 28.8 and 10.2% with air feed flow of 50 Nm^3/h at 623 K and 20 kg of biomass.

A significant part of Chilean industry is based on cereal plantations and forestry activities. These industries produce large amounts of residuals which are a major source of biomass. In order to evaluate the employment of these sources for hydrogen production using hybrid filtration combustion, a selection of the most common biomass sources in Chile is achieved considering that forestry plantations are mostly focused on insignis pine (Pinus radiata) and shining gum (Eucalyptus nitens) [27] and cereal plantations are focused on oat and wheat cane, showing also the differences between several biomass sources. The availability of these biomass sources makes their use very attractive for energy and syngas production, finding an innovative use of a residual material and diversifying the sources of hydrogen and syngas, especially considering that these biomasses are usually burned as waste without any further purpose. Thus, the usage of hybrid filtration combustion for these biomass sources is motivate by the description of the process with different feedstock to analyze the differences among them using the advantages of the technology for the conversion of the solid fuel given by the inert solid fixed bed surrounding it.

This work assesses the use of the most common and available biomass sources from industrial residuals in Chile, for the production of syngas using hybrid combustion filtration with 50% of the porous media volume reactor occupied by biomass, and the influence of the gasifying agent is evaluated by using a mixture of natural gas–air ($\Phi = 1.1$) and a steam–air flow as an oxidant, varying filtration velocity. This work can be divided into two parts: Part 1: usage of natural gas–air premixed filtration combustion and Part 2: using a saturated steam–air mixture and varying filtration velocity. Temperature and product characterization are obtained experimentally to describe and evaluate hydrogen and syngas production.