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# Syngas production from polyethylene and biogas in porous media combustion

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## ABSTRACT

The production of syngas from biogas (surrogate of CH<sub>4</sub>/CO<sub>2</sub>: 55/45 v/v) and polyethylene in a porous media combustion reactor is experimentally studied. The employed setup is novel and has not been studied before. A semi-continuous feed of solid fuel and a constant filtration velocity of the gaseous reactants of 17 cm/s were considered. Temperature, velocity of propagation, and composition of the syngas produced in the combustion waves were registered in a tubular reactor packed with a ceramic foam porous medium and two solid fuel inlets. In the first part of the study, a baseline determined by the filtration combustion of a biogas/air mixture through the ceramic foam at the equivalence ratio ( $\phi$ ) range  $0.7 \leq \phi \leq 1.6$ , having transient (upstream and downstream) and stationary combustion wave propagation regimes, is established. In the second part of this work, portions of the ceramic foam in two different separated zones are extracted, leaving space for the semi-continuous supply of polyethylene. In this second part the biogas-air combustion was performed only for  $\phi = 0.8$  and  $\phi = 1.6$ . Although the combustion temperature decreased by the presence of polyethylene, it was found that the syngas (both H<sub>2</sub> and CO) yield was larger than for the baseline. The highest degrees of conversion to hydrogen and carbon monoxide was reached under the presence of polyethylene, having 45% and 67% for  $\phi = 0.8$ , and 45% and 60% for  $\phi = 1.6$ , respectively. These results are very promising and they demonstrate the capabilities of the presented methodology and experimental setup, which should encourage future attempts of applications of the technology.

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## Introduction

The global energy scenario goes through a critical situation as a consequence of a number of sociopolitical factors enclosing the increase of energy demand in developed and emerging economies (set to grow by 37% by 2040) and an attenuated but continuous population growth [1]. Fossil fuels still represent 87% of the primary energy consumed in the world, with its corresponding environmental impact and progressing

scarcity of resources -estimated annual decline rate of 2–3% since 2010 [2]-. In this context, a transition to alternative, renewable, clean, efficient, and sustainable energy sources is crucial and highly desirable.

Hydrogen is expected to play a significant role in the future energy scenario, since it can be used in most energy-demanding sectors, it can be stored in large quantities for long periods without significant losses and its end-use is nearly free of emissions of CO<sub>2</sub>, acid gases and other

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pollutants [3]. Evidently, the effective and clean production of hydrogen represents a key factor for the deployment of a hydrogen-including economy. Currently, different commercial processes produce hydrogen for the chemical industry, including water electrolysis and thermochemical splitting, photoelectrochemical, biological and photobiological processes and fossil fuel reformation processes [4]. Unfortunately, several of these processes are not expected to be technically available for large-scale implementation within the next decades, being this especially true for thermochemical water splitting, photoelectrolysis, biophotolysis and fermentation. Thus, new means and methodologies are required. Currently, the most technologically mature technique for large-scale hydrogen production is the direct chemical conversion of fossil fuels to hydrogen by means of catalytic partial oxidation (CPO), steam reforming (SR) and autothermal reformation (ATR) [3].

Additionally, due to the continuous rate at which municipal solid waste generation grows worldwide new alternatives for reducing, reusing, recycling and recovering are needed, being among typical alternatives combustion and gasification. In this context, some of the typical components of municipal solid wastes seem to be more appropriate for the latter. This is the case of polyethylene, which presents a greater heating value (average LHV of 40 MJ/kg) than other residues such as cellulosic waste (cardboard i.e. has an average LHV of 16 MJ/kg). Moreover, polyethylene has the potential of achieving higher hydrogen yields when subjected to pyrolysis and gasification processes which may be attributed to the large H<sub>2</sub> content revealed by an elemental analysis of polyethylene [4]. The polyethylene pyrolysis is the process of thermal degradation of long hydrocarbon chains in absence of gas-producing agent and it has been reported that the pyrolysis of plastics such as polyethylene or polystyrene almost yields a 99% of the mass to volatile products, leaving about 1% of ashes and carbonaceous material [5]. The advantage over combustion is the reduction of volumetric gaseous products in a factor from 5 to 20, which at the same time reduces the size of gas reconditioning equipment [6]. The pyrolysis kinetic of high density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP), and polystyrene (PS) has been successfully described below 450 °C [7]. Additionally, pyrolysis and gasification of polystyrene have been studied in a semi-batch reactor at temperatures of 700, 800 and 900 °C. It has been shown that the gasification of PS produces less amount of syngas than pyrolysis at 700 °C, while at 900 °C it generates a larger quantity of syngas than pyrolysis [5]. Plastic pyrolysis and gasification have been largely studied in fluidized bed reactors, and, more recently, conical spouted bed reactor (CSBR) have been also investigated [8]. A very comprehensive review [9] has been recently published, which presents the main waste plastics valorization routes to produce syngas covering different gasification strategies and other novel alternative processes, such as pyrolysis and in-line catalytic steam reforming. The main conclusion of that review is that air gasification is the most studied and developed strategy and it pursues the production of a syngas for energy purposes, while a deepest development of other promising alternative as pyrolysis and in-line reforming is required. More details about this can be found in Ref. [9] and references herein.

Thus, in the current energy scenario, the demand for efficient and eco-friendly hydrogen production schemes becomes increasingly significant. In this context, the generation of hydrogen by means of gaseous fuel reforming in a porous medium has been proved to be one of the feasible options to tackle environmental and fossil resources problems. On the other hand, inert porous media combustion is a technology that has shown to be an interesting and alternative to produce hydrogen and a feasible option to deal with clean energy demand issues [10]. This technology has been extensively studied by means of theoretical and experimental means, considering the combustion of several gaseous and a few liquid fuels [11–21]. In these studies, transient and stationary approaches for the propagation of the combustion wave have been employed. The large heat capacity of the inert solid induces an internal process of heat recuperation allows the achievement of a self-sustaining reaction over a wide range of equivalence ratios [22]. In this process, both the porous media and the reactant gas play important roles and partial oxidation processes in porous medium may be defined as the propagation of an exothermic chemical reaction of a gaseous fuel through a chemically inert solid [10]. For this reason, using its characteristics to reform solid fuels is an attractive concept that has been developed within the approach of hybrid filtration combustion, where the inert solid is homogeneously mixed with solid fuel pellets in a batch configuration, taking advantage of the several conditions that the porous medium adds to the reformation process of the solid fuel while a gasifying agent/fuel-air mixture is filtered and a combustion wave is created. Hybrid filtration combustion has been studied for syngas production using carbon [23], wood pellets [24–27], coal [28–30], polyethylene [31], algae [32], among other solid fuels, showing up the potential and flexibility that the technology presents for hydrogen and syngas production. Carbon-rich solid fuels are exposed to high temperatures in order to produce a gas mixture mainly composed by carbon monoxide and hydrogen. Gentillon and Toledo [31] reported the pyrolysis of HDPE aiming to produce syngas from the filtration combustion of propane through a solid matrix containing polyethylene and alumina spheres. The model assumed complete pyrolysis in the batch type reactor and considered that volatile products were ethane, acetylene, and ethylene. Several series of experiments were performed in a hybrid porous reactor. The evolution of temperature, combustion wave and syngas composition was registered in a range of equivalence ratios from 1 to 1.65 achieving hydrogen and carbon monoxide conversions of 48% and 89% respectively. Nevertheless, the configurations presented by hybrid filtration combustion consider only a batch mixture of solid fuel and inert solid.

The main objectives of the present work are 1) Proposing a new configuration for a semi-continuous supply of solid fuel in a reactor, which can provide the conditions of inert porous media combustion, and 2) Demonstrating the technical feasibility of the technology, being in this way a first step in its development. To the author's best knowledge, this configuration has not been proposed before, which highlights its novelty. More specifically, the gasification of polyethylene pellets by a filtration combustion wave of biogas/air is analyzed in the proposed reactor. The temperature profiles,

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