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Hydrocarbons conversion to syngas in inert porous media combustion

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ABSTRACT

Experimental combustion in inert porous media of Liquefied Petroleum Gas (LPG), Butane, Propane, Diesel Fuel and Heavy Fuel Oil (HFO) is presented to assess the syngas production within different stages of refinement of fuels, considering light gases up to a residual oil. The porous media is composed by a fixed bed of alumina spheres and temperatures and gas composition were acquired while stable combustion waves under rich fuel conditions were produced. The results of this study showed that it is possible to partially oxidize HFO producing up to a 10% of H₂ and CO in the products for the equivalence ratio of $\phi = 1.3$, with a superior performance than any other fuel tested in this work. The behavior of the recorded temperature results showed good agreement with the available literature. Upstream regimes of propagation of the combustion wave are observed for the experiments with liquid fuels, while gaseous fuels presented downstream regimes for $\phi > 2$ up to $\phi = 4$. Results suggest that in order to efficiently transform the fuels into syngas, it is convenient to operate the reactor under an upstream regime considering the chemical energy at inlet and outlet. Furthermore, liquid fuels, regardless of its refining level, have the potential to produce syngas in inert porous media in promising volumes.

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Introduction

Efficient use of the hydrocarbon resources provided by the planet is a priority. An increase on the awareness on global warming has also increased the regulations over the use of certain energy resources in order to control the emission of

pollutants that influence environment and health issues. Although, human activities massively demand the use of energy in several formats depending on the different requirements of the task. Therefore, refineries supply a variety of hydrocarbon fuels that come from petroleum oil that are suitable for almost every requirement. Nevertheless, these

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refining processes leave a residual, which is not desired since it carries unwanted elements that are harmful when used. Furthermore, its use is related mostly to situations where the pollutant emission standards allow its use, such as the combustion in ships or in places where expensive mitigation measures can be taken, which implies a low cost of the fuel. On the other hand, refineries require hydrogen as a part of their key processes such as hydrodesulphuration that is a widely used process to reduce sulfur presence in commercially available hydrocarbon fuels or, hydrocracking, where the heavy hydrocarbon compounds of petroleum are cracked into lighter and more valuable fuels in the presence of hydrogen.

Several processes are available for hydrogen production and one of the most promising is the partial oxidation in inert porous media. Currently, a considerable amount of information on combustion in inert porous media burners is available, having several reports regarding the working basis and design principles of the technology, describing construction materials and porous structures used, characterization of emissions and their control, several modern applications of the combustion technology and innovative approaches have been presented [1–9] mostly for common gas fuels.

This technology eliminates or significantly reduces effects caused by some of the disadvantages of the free flame combustion such as: high pollutant emissions, low energy density, small range of thermal power variation, problems with stability of the flame, strong dependence on the type of fuel and a limited range of variation of the equivalence ratio. Most of these problems are related to the flame and the low thermal conductivity of the gases involved. Therefore, the presence of inert solids that enhance the thermal conductivity at high temperatures is suitable, also considering that the filtration of the gases through the porous boosts mixing and diffusion [1,10].

On the other hand, the partial oxidation of liquid fuels in a porous media is a promising technique for the reforming of hydrocarbon fuels into syngas, especially to obtain hydrogen in fuel-rich conditions [11]. Syngas can be a source of hydrogen for fuel cells, enrichment of conventional fuels or it can be used to produce high quality fuels from low energy content or neutral carbon dioxide sources. Liquid fuels have a highly developed infrastructure, considering the extraction, refining and distribution and also, being easy to manipulate and store providing high energy densities. Pastore and Mastorakos [12] studied the rich n-heptane and diesel combustion in two-layer porous media in stable operation for syngas production. Considering equivalence ratio $\phi = 2$ for different thermal input values, the results for n-heptane showed that the reformer can produce syngas with concentrations of 12.6% and 15% of H_2 and CO respectively, about 80% of the corresponding values expected from thermodynamic equilibrium at the sample temperature. Diesel reforming tests were performed at a higher preheat temperature and with a different ceramic foam for the reforming stage. The reformate analysis showed a reforming efficiency up to 77.6% at $P = 9$ kW and $\phi = 2$, with H_2 and CO concentrations of 15.2% and 19.1%, respectively. Subsequently, they reported the rich combustion of n-heptane, diesel, kerosene and biodiesel EMR to produce syngas suitable for the cleaning and separation stages for fuel

cell application or the enrichment of conventional burners. Rich combustion waves were stabilized in a two-layer inert porous medium combustor and a range of ϕ and porous materials were reported. n-heptane was successfully reformed up to $\phi = 3$, reaching a conversion efficiency (based on the lower heating value of H_2 and CO over the fuel input) up to 75% for a packed bed of alumina beads. Also, diesel, kerosene and bio-diesel reformed to syngas in a zirconia foam burner showing conversion efficiencies over 60% [13].

An experimental and numerical study regarding the conversion of liquid heptane to syngas through combustion in porous media was presented by Dixon et al. [14], showing that at a constant inlet velocity, hydrogen production is enhanced by increasing ϕ , whereas hydrogen conversion efficiency reaches a peak value around $\phi = 3$. Tests at $\phi = 2.5$ showed that the conversion efficiency increases with the reactants' inlet velocity and values higher than 80% are obtained for the highest tested velocity of 80 cm/s. Similar trends for carbon monoxide conversion and energy efficiencies are observed, where peak values exceed 90% and 80%, respectively. Also, the results indicate favorable conditions for fuel reforming for $2.5 \leq \phi \leq 3.5$, having that the inlet velocity has a significant effect on the performance of non-catalytic fuel reforming. Substantial efficiency gains are observed for increased inlet velocities, which are attributed to cause an increase in the temperature of the reactor.

Non-catalytic conversion of jet fuel and butanol to syngas by transient filtration combustion over a variety of ϕ and inlet velocities were described by Smith et al. [15]. In particular, the results of the total energy conversion efficiency for jet fuel showed that it increases with ϕ up to a peak of 61% at $\phi = 3.15$. For butanol, the total energy conversion efficiency determined experimentally followed the equilibrium value until $\phi > 3$; for this condition, experimental conversion efficiency continue increasing up to $\phi = 3.5$, where values higher than 100% were found. For that reason, an unbalance in soot deposition and consumption at the time of exhaust gas sampling is suspected.

The thermal partial oxidation (TPOX) of diesel fuel for the production of syngas, considering different values of excess air ratio, was studied theoretically and experimentally by Al. Hamamre et al. [16]. The processing of fuel, previous to inlet to the porous media reformer, includes atomization, evaporation, and formation of a homogeneous fuel-air mixture. It is noted that the preparation of the fuel-air mixture is a major factor that influences the quality of the reforming process. The porous media was a ZrO_2 foam of 10 ppi. The results in the porous-based TPOX burner showed that a practical operating condition can be achieved at $\phi = 2.22$ –2.5. The maximum H_2 and CO concentrations were achieved at $\phi = 2.22$, observing that for lower ϕ values the syngas concentrations decreased due to the formation of CO_2 , and for ϕ values higher than 2.22, higher concentrations of CH_4 and C_2H_2 were detected, and consequently, the concentrations of H_2 and CO decreased. For 873.15 K air preheating temperature the H_2 and CO molar fractions were 16.0% and 18.5%, respectively [16].

Taking in consideration that several fuels with different characteristics are commercially available, mostly coming from the derivatives of oil distillation and refining and the limited volume of literature available on liquid fuels reforming

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