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Design and Development of a 25 kW Diesel Fuel Processor

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1 Introduction

Reforming processes consist of the chemical transformation of hydrocarbons to produce hydrogen by means of thermocatalytic reactions [1]. Although using diesel fuel for hydrogen production implies lower performances in the whole process, respect to gaseous fuels, it has the advantage of a higher energetic density, which favours storage in reduced volumes and it also has a distribution infrastructure all over the world.

INTA, CIDAUT, ICP_CSIC and AICIA are collaborating in a pre-commercial system of a hydrogen production diesel Oxidative Steam Reformer coupled to a 25 kW PEMFC, evolution of a previously 5kW prototype [2]. This system had a flexible design, which allowed the characterization of each reactor separately and jointly, without taking into consideration maximum efficiency. In the last years, a 25 kW fuel processor has been developed and tested. This system is autonomous, has a high level of thermal integration, reduces slightly start-up, stop and transitory times; and improves hydrogen concentration. CIDAUT has the responsibility of plant development and reactors design, whereas ICP-CSIC develops the different catalysts and AICIA will integrate the 25 kW PEM Fuel Cell next year.

2 Experimental

The fuel processor is composed by a set of reactors, a series of auxiliaries and instrument and control equipments. The auxiliaries guaranteed the adequate feeding currents to the reformer, the heat of the system, the cool reforming of gas outlets, maximise the thermal efficiency of the fuel processor, and includes secondary processes for increasing the useful life of the catalyst as inertization, catalyst cleaning, or system cooling.

The set of reactors is formed by:

- An OSR (Oxidative Steam Reforming) reactor, where the primary hydrogen production from diesel takes place. Air and water are also introduced as reactants. In this reactor diesel reacts with air and water following the reaction:

  $$C_nH_m + a\bullet n\ (O_2{+}3.76N_2) + b\bullet n\ H_2O \Rightarrow p\ CO + q\ CO_2 + r\ H_2 + s\ H_2O + a\bullet n\bullet 3.76\ N_2$$

  where ‘a’ is the oxygen to carbon ratio and ‘b’ is the water to carbon ratio. The target values for O2/C ratio range from 0.45 to 0.5 with a H2O/C ratio next to 3. The homogeneous mixture of the reactives and the vaporisation of the diesel fuel take place by means of a swirl effect inside the mixing chamber, and using also pre-combustion reactions that occurs around 400 – 500 ºC denominated cold flame [3]. The OSR reactor operates at temperature higher than 800 ºC to avoid ethylene formation. The catalyst formulation used in this reactor is a cobalt based catalyst derived from perovskites precursors with improved thermal and coke resistance.

- A Desulphuriser working around 300 ºC and with the goal of sulphur removal from the reforming gas outlet by means of adsorption of the formed H_2S.
- A WGS (Water Gas Shift) Reactor, which is in charge of the CO selective conversion via its oxidative reaction with water to obtain CO_2 and H_2. The used catalyst is based on Pt deposited on mixed CeO_2–TiO_2, operating at 275 ºC.
- A Prox (Preferential Oxidation) Reactor performs the selective removal of CO by direct oxidation with air. The catalyst is a monolith that contains highly dispersed Pt on alumina, working between 150 - 175 ºC with an O_2/CO ratio ranging from 1.3 to 1.

Table 1: Typical approximate compositions on dry basis at the outlet of each reactor.

	H_2	N_2	CO_2	CO	CH_4	C_2H_4
OSR Reactor	30 %	49 %	14 %	7 %	1 %	<500 ppm
WGS Reactor	36 %	Balance	21 %	0.3 %	1 %	<500 ppm
PrOx Reactor	36 %	Balance	21 %	<50 ppm	1 %	<500 ppm

The scheme in Figure 1 presents the input of reactive currents (diesel, air and water) inside the mixing chamber and from there to the OSR Reactor and the rest of reactors. Air could be preheated with a heat exchanger that cools the gas reforming at the output of the WGS reactor. Water is preheated basically by two heat exchangers: a first one cools the gas reforming stream at the output of the OSR Reactor, while the second one cools the combustion gases produced in the burner for adapting them to the Desulphuriser temperature. A second air flow is added to the PrOx Reactor, which by means of the O_2/CO ratio at the input, controls the CO composition in ppm's of the reforming gas at the outlet of this reactor. A diesel burner (which can also run on reforming gas) is entrusted to supply heat for the system starting-up and to control the temperatures of the reactors.

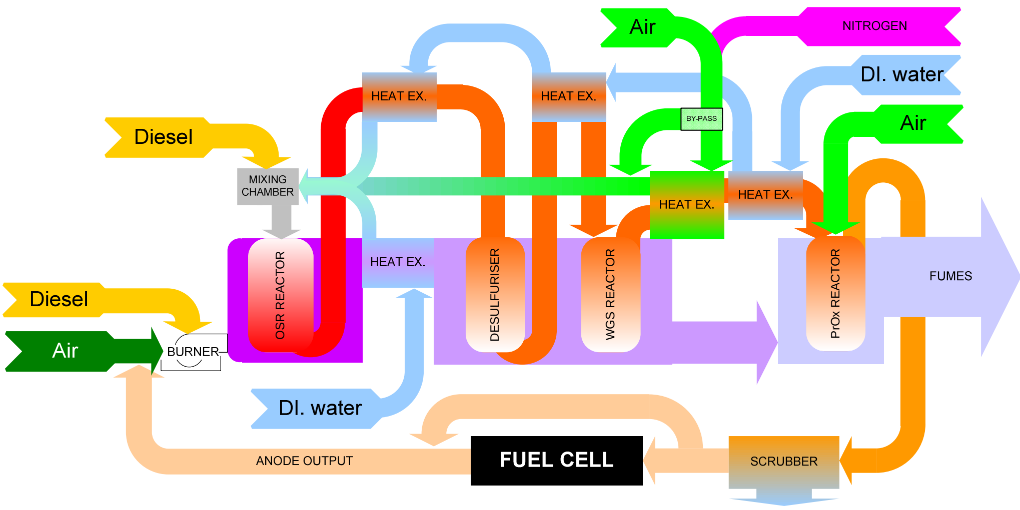

Figure 1: Working scheme of the 25 kW fuel processor.

After the PrOx Reactor, the reforming gas is cooled by means of a scrubber and a coalescent filter, with the aim of condensing and recovering the excess of water contained in this flow [4]. Afterwards, if it fulfils temperature, humidity and gas composition conditions set by the PEMFC manufacturer, the reforming gas is conducted to the fuel cell. If it does not, it can be expelled to the environment (burned by a flare), or fed to the boiler's burner that heats the system. Moreover, the outlet of the fuel cell anode could be introduced in the air current that feeds the diesel burner for increasing the global efficiency of the system.

One of the design critical issues was the burner design and the study of heat transfer in the OSR reactor. For solving that, a fluid-mechanical model of the reactor-burner set was accomplished, taking into account not only mass and energy transport but also reaction kinetics of the reactor. The whole model was fit and validated through a series of experimental tests in the 5 kW facility [5]. Figure 2 presents results from this simulation. Figure 2.a shows temperature profile inside the OSR reactor and Figure 2.b includes also the flow lines and temperature of the fumes.

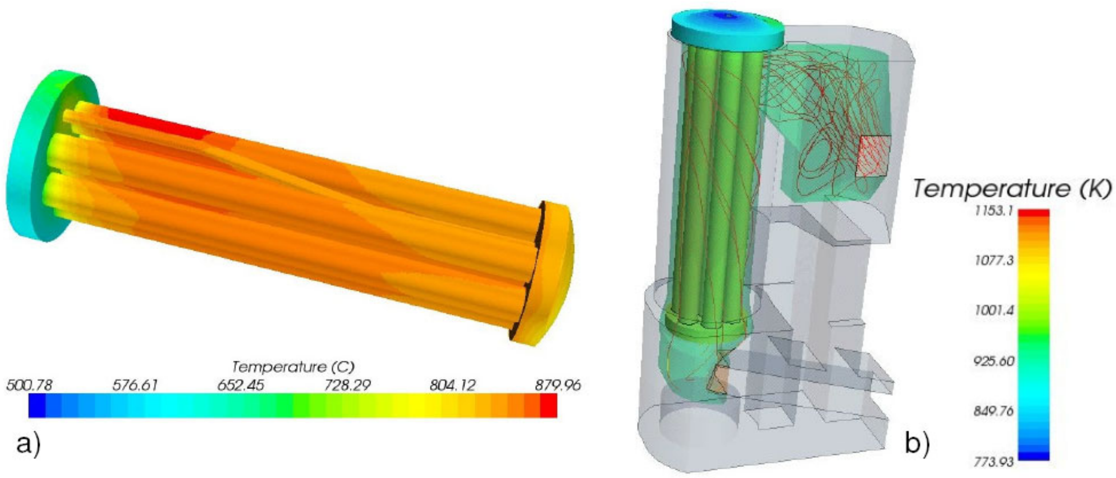

Figure 2: CFD simulation results; a) OSR temperature profile, b) General view of the simulation, including flow lines and temperature of combustion gases.

Another critical point was the physical design of the set of reactors and the PrOx Reactor. A 3D design tool and a tensile and materials study were used for this issue (Figure 3).

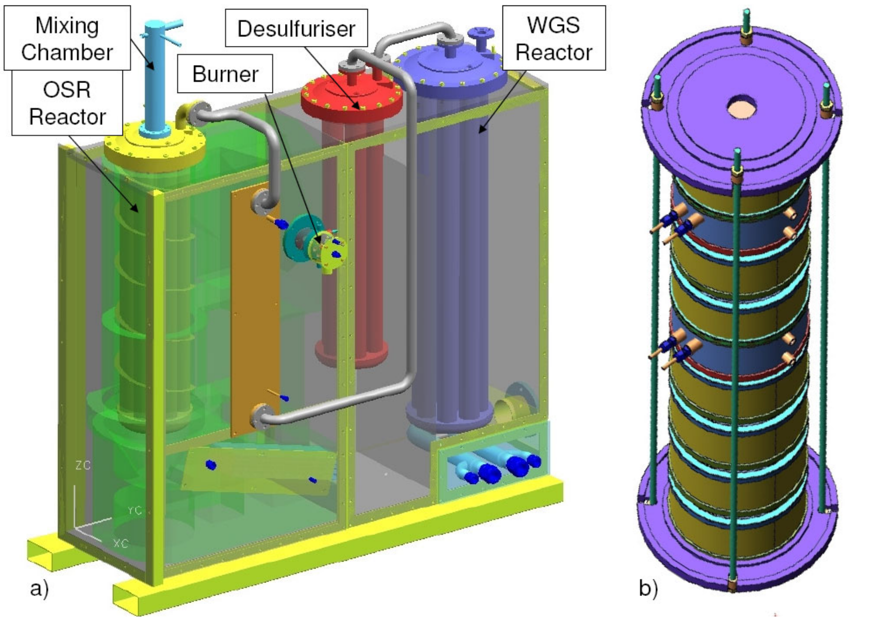

Figure 3: 3D views of a) reactor set, and b) PrOx reactor.

Figure 4 shows several photographs of the whole facility and of the set of reactors.

Figure 4: Fuel processor facility; a) Exterior view of the cabinet, b) Instrumentation of feeding lines and cooling of the reformer, c) set of reactors and scrubber, d) Gas measurement systems and water line, e) electric enclosure and control system.

3 Results

Figure 5 shows results from a typical test, working the facility at 12 kW. Horizontal axis of each graph represents time in seconds. Figures 5.a and 5.c show temperature profiles of each reactor of the fuel processor. As it can be observed, OSR reactor temperatures lie inside the 800 – 900 ºC range, except T_OSR3 and T_OSR3' (placed in the lower part of the reactor) that, due to thermal inertia, need more time to reach the optimum. WGS reactor and desulphuriser temperatures are inside their working zone, while PrOx reactor temperatures are slightly lower than 150 ºC. In this condition, the PROX reactor is able to decrease the CO concentration below 50 ppm. Graphs 5.b and 5.d present the evolution of the gas reforming compositions throughout the fuel processor and some significant data as water, air and diesel flows, O_2/C and H_2/C ratios, and system pressure. It can be seen in these graphs that hydrogen composition decreases when O_2/C ratio increases, with CO concentration around 5 %.

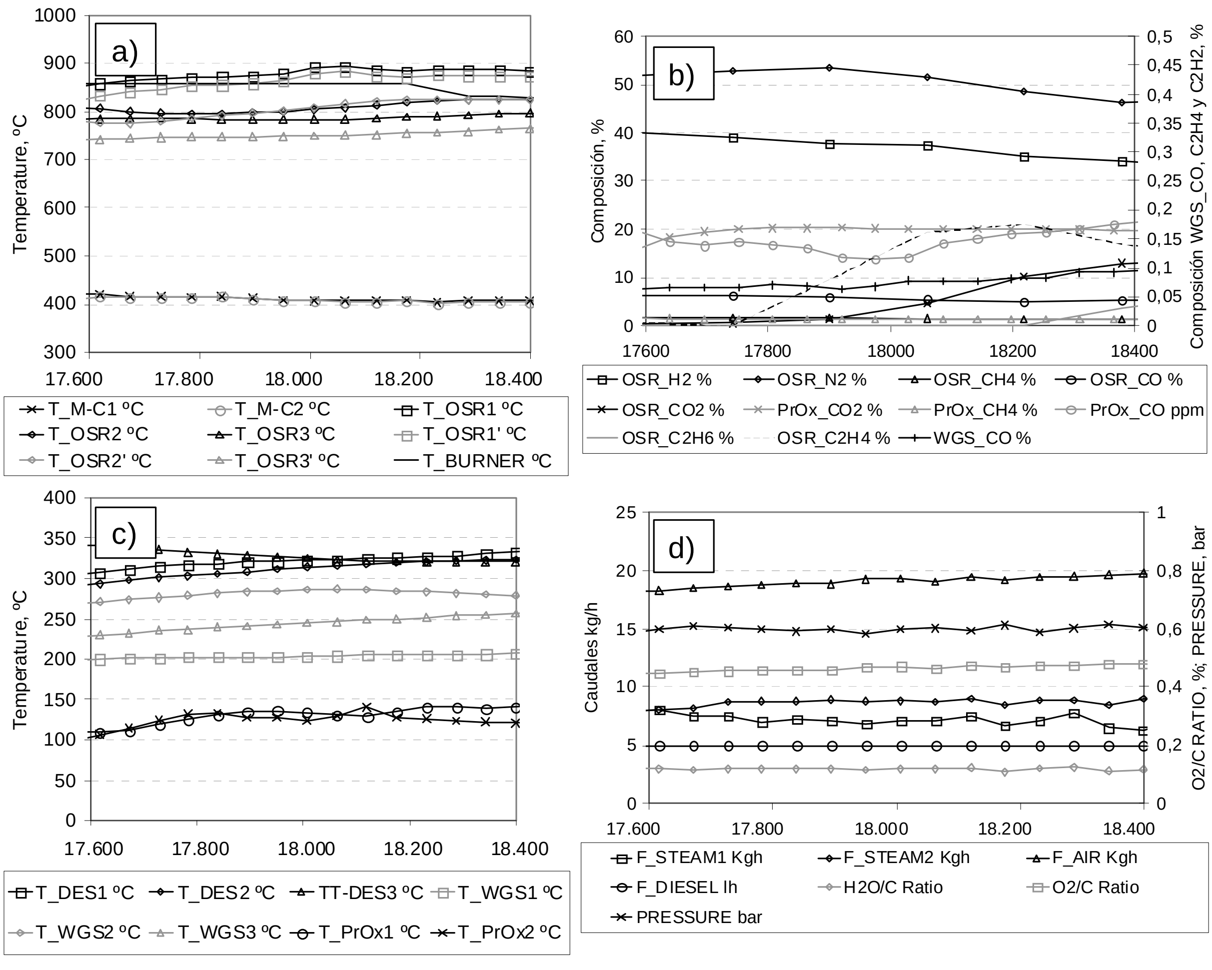

Figure 5: a) Temperature profile in Mixing Chamber (M-C) and OSR Reactor; b) Temperature profile in Desulphuriser and WGS and PrOx Reactors; c) Gas composition in several points; d) several physical variables evolution.

4 Conclusions and Future Works

A fuel processor able to process diesel, and producing a gas stream to be used in 25 kW PEMFC has been developed. Tests for tuning the facility and design validation of each reactor have been carried out.

The fuel processor will be moved to INTA facilities in May, when a test plan for different working conditions will start to be accomplished.

References

[1] C. Pereira, J-M Bae, S. Ahmed, and M. Krumpelt. *"Liquid Fuel Reformer Development: Autothermal Reforming of Diesel Fuel"*. Hydrogen Program Technical Review. California, 2000.

[2] D. Sopeña, A. Melgar, Y. Briceño, R. Navarro, C. Alvarez, F. Rosa Iglesias. *"Diesel Fuel Processor for Hydrogen Production for 5 Kw Fuel Cell Application".* International Journal of Hydrogen Energy . Vol. 32. No. 10-11. 2007. Pag. 1429-1436

[3] Hartmann L, Lucka K, Köhne H. *"Mixture preparation by cool flames for diesel-reforming technologies".* J Power Sources 2003;118:286–97.

[4] D. C. Kincaid, T. S. Langley. *"A Water Droplet Evaporation and Temperature Model"* ASAE (Vol. 32, No.2, pp. 457-463, 1979).

[5] Liu DJ, Kaun TD, Liao HK, Ahmed S. Characterization of kilowattscale autothermal reformer for production of hydrogen from heavy hydrocarbons. Int J. Hydrogen Energy 2004;29:1035–46.