FERRET

A FLEXIBLE NATURAL GAS MEMBRANE REFORMER FOR M-CHP APPLICATIONS

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WP6 – Integration and validation of FERRET CHP-system

D6.6
Public report on effective integration and performance of the system

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	
CON	Confidential, only for members of the Consortium	

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(**) indicate the acronym of the partner that prepared the document

Content

1 EXECUTIVE SUMMARY

1.1 Description of the deliverable

This deliverable concerns tests performed on the Ferret CHP systems at ICI laboratory. After receiving the system from HyGear it was installed and preliminary tests were carried out in order to check the membrane state. No damage occurred during the transport, thus experiments were performed on the Ferret unit.
After this first test campaign, a technical action to improve purity of permeate was investigated.

2 INTRODUCTION

Work performed in previous WPs and tasks of WP6 was aimed to develop and manufacture Ferret unit and to test the whole assembly checking for bottleneck and verifying the correct operations of the system.
This deliverable describes testing activity carried out at ICI laboratory, where Ferret CHP system was evaluated on its proper operation.
The objectives of activities at ICI were addressed to test the system with the Italian natural gas. In particular the tests were focused on:
- evaluation of Ferret unit at different operating conditions;
- evaluation of ATR reactor performances;
- evaluation of whole CHP system performances and efficiencies.

3 SYSTEM INSTALLATION

Figure 1. Ferret unit delivered to ICI, with intact ShockWatch

Ferret unit was shipped from HyGear to ICI by a special transport with the anti-vibration system to safeguard membranes in the ATR reactor, in order to be sure the system reach ICI facilities in good conditions.
A ShockWatch was incorporated on the shipping crate in order to detect possible strike. Upon receiption of the Ferret unit, shock detector was intact, showing no shock indication.

ICI laboratory was prepared in order to receive the system and provide the installation in the shortest time.

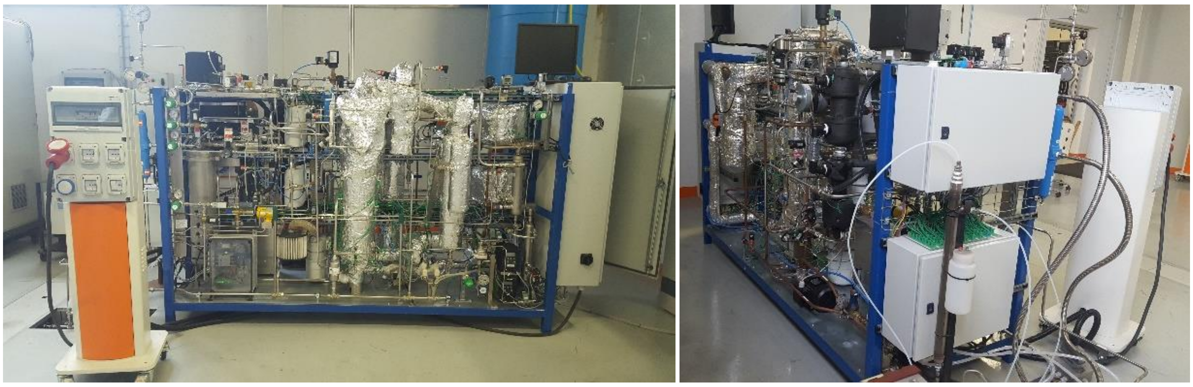

Figure 2. Ferret unit installed at ICI laboratory

The system was connected to high pressure gases lines (N_2, Air and Natural Gas) and to water lines (demi water for catalytic process and coolant water). It was connected to power electric grid, and was cabled to an emergency shutdown button. Finally it was cabled with a LAN connection. All the technical aspects regarding commissioning in this stage have been promptly addressedand the system was ready to start.

4 EVALUATION OF FERRET UNIT

4.1 Reference test run

Before starting with hydrogen generation, a preliminary test on membranes leakages was performed remotely by HyGear.
The aim of this evaluation was to check membranes state, in order to understand if the transport had caused damaged to the membrane. This test consisted to feed the membrane reactor with pressurized nitrogen, measuring the flow rate passed through the membranes toward the permeate side. The values measured showed the same results obtained at the facilities of HyGear before the shipment. This meant no damage to the membranes had occurred during transport.
The fuel processor part was ready to be evaluated. The fuel cell stack however was not connected due to a leak in the stack had been observed during the previous tests in The Netherlands, therefore the stack was not approved for operation for safety reasons.

The first-run of the system at ICI was performed with the support of HyGear, who showed how to manage and maintain the system. After checking of all the connections, the tuning of the inlet gasses pressure level, and setting of many other system parameters, the membrane reactor was finally started. To speed up the test, the first tests have been performed using nitrogen like sweep gas instead of steam

4.2 Test without sweep and with nitrogen as sweep

In agreement with HyGear, the testing conditions were defined, and initial test was performed as reference in order to have a comparison with experiments performed at HyGear premises.

During the test campaign the system had to be stopped a few times due to issues with filters being clogged with carryover from the fluidized bed. The issue of particle separation proved to be an aspect not to be neglected, and this aspect had been described as an aspect to be improved in future versions of the unit.

Summary of tests performed and their results are represented in Table 1 and Table 2.

Table 1. Summary of testing parameters

Test	#	1	2	3
P ret in	[bar,a]	8.0	8.15	8.1
T	[°C]	550	550	550
NG	[slm]	15	15	15
S/C	-	2.1	2.1	2.1
H2O sweep	[l/h]	-	-	-
N2 as sweep	[slm]	3.59	-	-
Air	[slm]	44.2	44.3	36.6
H2O process	[l/h]	1.8	1.8	1.8
Permeate	[slm]	18.1[1]	12.7	14
Retentate	[slm]	58.5	58	54.7
p per in	[mbar,g]	38.6	33.7	31.8
p per out	[mbar,g]	34.4	31	28.9

Table 2. Summary of permeate and retentate composition

	Test	1	2	3
Permeate before Met	H_2	54	79.4	83.27
	CO_2	2.6	4.1	3.7
	CO	0.47	1.11	1.2
	CH_4	1.32	2.33	1.93
	O_2	0.26	0.08	0
Permeate after Met	H_2	50.2	79.37	82.4
	CO_2	2.4	3.9	3.4
	CO	-	0.3	0.3
	CH_4	2.22	3.19	3.31
	O_2	0.18	0.07	0
Retentate	H_2	15.6	16.58	20.4
	CO_2	15.2	14.1	15.3
	CO	1.02	1.09	1.6
	CH_4	8.45	9.73	9.45
	O_2	6.34	0.12	0

All the tests were performed setting up the same temperature, pressure and reactant feedings. Test #1 was performed with nitrogen as sweep. It results in a dilution of permeate decreasing species concentration values. Tests #2 and #3 were performed without sweep. Data of tests #2 and #3 was recorded during the same test. Data of test #2 have been recorded immediately after the system started to produce hydrogen, while data of test #3 were recorded after half an hour.

[1] Excluding sweep

From data acquired it seems that CO before methanator is quite high. This was caused probably by high leakage of one membrane or membrane sealing.
At the same time it is possible to see that the amount of CO out of the methanator was still high, as pointed out by HyGear in D6.4, and was not suitable to satisfy requirements for the PEM fuel cell.
Originally the tests with maximum temperature of 600 °C were expected to be carried out at ICI, but the consortium agreed to not increase the temperature over 550°C in order to avoid detrimental effects on membranes precluding the correct operation of the system.
Table 3 summarizes some indexes resulting from data analysis.

Table 3. Summary of testing results

Test	H_2Prod	HRF	HSF	HC	H_2permenace
#	[%]	[%]	[%]	[%]	mol/(s m^2 Pa$^{0.5}$)*10^-4
1	52.8	29.1	55.1	65.3	4.1
2	49.2	24.2	49.1	60.4	5.7
3	52.8	26.0	49.2	63.7	4.2

For a detailed description of the following parameters see D5.3
H2 prod. = H2 productivity
HRF = hydrogen recovery factor
HSF = hydrogen separation factor
HC = hydrocarbon as C1 equivalent in the NG;

4.3 Testing with steam as sweep

Using steam as sweep stream, a new campaign test was performed. Data acquired during Ferret hydrogen production, are summarized in tables (Table 4 and Table 5)

Table 4. Summary of testing parameters with steam as sweep

Test	#	4
P ret in	[bar,a]	7.43
T	[°C]	550
NG	[slm]	15
S/C	-	2.1
H2O sweep	[l/h]	0.1
N2 as sweep	[slm]	-
Air	[slm]	44.3
H2O process	[l/h]	1.8
Permeate	[slm]	18.4
Retentate	[slm]	57.1
p per in	[mbar,g]	36
p per out	[mbar,g]	35

Table 5. Summary of permeate composition with sweep flow

	Test	4
Permeate before Met	H_2	85.4
	CO_2	3.6

	CO	0.18
	CH_4	1.48
	O_2	0.23

In agreement with the consortium the top part of the reactor was opened and was checked which membrane had the highest leak, with the purpose of blocking that membrane.

5 CONCLUSIONS

The Ferret unit was tested at ICI laboratory. It was a user friendly system, very easy to manage due to the start, stop, reset and emergency buttons.
The system had to be tested without the stack, therefore the analysis had focus on the innovative aspect of the system which is the membrane reactor fuel processor.
Improvement on this system bottleneck are suggested for future developments, mostly regarding filtration of the fluidzable catalyst, and optimization of methanator working parameters (temperatures) in order to achieve lower CO concentration.
It was possible to appreciate the strength of the system to produce a good hydrogen flow in only one step (shifting all the possible H_2 production trough membranes) compared to traditional multistep fuel processor and to work with different natural gas compositions (as described in public deliverable D5.4 Public report on evaluation of pilot scale catalytic membrane reformer).