HYGRID

FLEXIBLE HYBRID SEPARATION SYSTEM FOR H2 RECOVERY FROM NG GRIDS

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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 content and purpose

This document describes the tests with the HyGrid TSA prototype. The pilot scale TSA system was designed for a production capacity of 25 kg/day of hydrogen and capable of purifying the product to a dew point (water content < 5 ppm) suitable for use as fuel for fuel cell vehicles.

1.2. Brief description of the state of the art and the innovation brought

By using steam as a sweeping gas in the Pd membrane unit, the recovery of hydrogen can be optimized. This necessitates the incorporation of a dryer, to meet dew-point specifications for the hydrogen product. The innovation brought by the TSA development are improved understanding of the adsorption kinetics of the hydrogen TSA. The size and cycle time of TSA can be improved and optimized leading to lower CAPEX and OPEX.

2. INTRODUCTION

This Deliverable report describes tests performed with the stand-alone TSA pilot plant at HyGear. The TSA has been designed to be integrated with the Pd-membrane module and EHP unit later on of partners Tecnalia, TU/e and HyET.

The aim of the tests is:

- to demonstrate that the TSA meets the design specifications and to investigate the influence of process parameters on the performance
- to improve the TSA model developed within the project.

3. DESCRIPTION OF THE TEST SYSTEM

The PFD of the TSA system is shown in Figure 1.

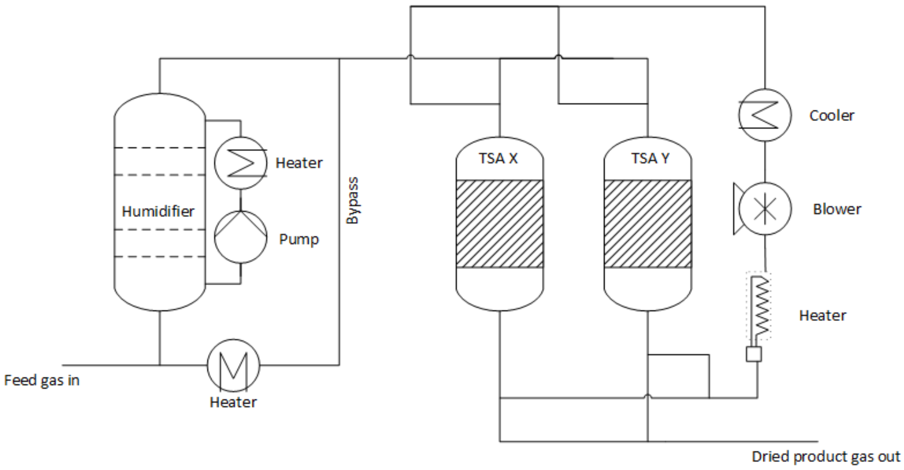

Figure 1: Simplified PFD of a TSA

The test system contains of a number of TSA vessels; during operation, one vessel is in adsorption mode while (the) other(s) are either being regenerated, or in stand-by mode. Each vessel is equipped with several valves for directing the gas flow in the right manner.

The bed size of the TSA was based on the expected water load for the integrated HyGrid prototype system. This system produces wet hydrogen, which is separated from natural gas by a Pd-membrane. By cooling down the wet hydrogen, most of the water (originating from the use of steam as a sweep gas in the Pd-membrane module) is condensed out and removed; the residual water vapour has to be removed by the TSA.

Regeneration is performed by circulating hot gas through the vessel; the gas is heated by an electric heater, passes through the vessel, and is then cooled back by means of a heat exchanger; desorbed water is condensed out and separated from the gas.

The TSA was tested with different gases that are brought to the desired moisture content in a humidifier. The humidifier consists of a packed column, that is operated with a large circulating flow of water. The water content and temperature of the feed gas to the TSA can be tuned to the desired value in a wide range.

The product humidity is continuously measured by means of a humidity sensor; this is used for determining breakthrough, and triggers the switching of columns. A large number of thermocouples is present in the adsorber vessels, which enables following the adsorption and regeneration zones.

The test rig was designed for the following working conditions:

Feed flow rate	5-15 Nm^3/h
Feed temperature	10-50°C
Feed water content	0.2%-1.2%
Pressure	0.0-0.5 bar(g)

4. TEST PROGRAMME

Main objective of the tests is to proof the performance of the TSA for the design conditions at the conditions for the HyGrid prototype. In addition, the influence of various process conditions on the performance is of interest to study possible process optimization and potential future design improvements and scaling-up rules. The following variables are of interest:

- Feed temperature
- Water content (feed dew point)
- Regeneration gas temperature
- Feed flow rate
- Influence of gas species (air or hydrogen)

5. RESULTS

5.1 Overview

The most important results from the variations of process parameters tested (after reaching stable cyclic conditions) are the adsorption time till breakthrough, which is used to calculate the cyclic capacity, and the product water content. Breakthrough was defined here as a concentration of 10 ppm in the product to enable comparison with the TSA model predictions.

An overview of the resulting adsorption capacities for the test variables listed compared to the base case is presented in below Table.

Table: Variation of water adsorbed as a result of varying operational parameters

Test	Description	Adsorption capacity variation compared to base case
#1	Base case (air)	
#2	Lower feed temperature	++
#3	Lower regeneration temperature	-/+
#4	Higher regeneration temperature	+
#5	Lower feed flowrate	+
#6	Increased feed flowrate, and higher regeneration temperature	-
#7	Low feed water content	++
#8	Influence of gas species	+

- : results in lower adsorption capacity compared to base case
-/+ : no significant deterioration or improvement compared to base case
+, ++ : results in higher (+) or much higher (++) adsorption capacity compared to base case

5.2 Model update

The test results were compared with the TSA model, developed within the project. The model includes an isotherm equation and a kinetic equation. The results of the tests performed in HyGrid showed that the kinetic parameter needed to be adapted from the original literature one. This became apparent due to the relatively high water content of the feed in the tests, which was outside the original model validation range. Final results show that the model predicts the obtained test results very well. The TSA model was used in the design of the beds.

6. CONCLUSIONS

Tests performed with the pilot plant TSA have proven that the unit functions satisfactorily. The required feed flow rates and water content can be handled, and the product dew point specification can be met. The TSA is ready for integration within the HyGrid pilot plant.

Testing the variable operational parameters showed that:

- a lower feed flow rate increases water adsorption capacity
- a too high feed temperature has a negative impact on the adsorption rates and thus lower adsorption capacity
- relatively high water content of the feed, causes relatively unfavourable adsorption kinetics and thus lower adsorption capacity
- regeneration gas temperature influences the baseline product water content but not the adsorption capacity
- the regeneration gas temperature can be lowered compared to the original expectation, while the product specification is still amply met. This leads to a lower energy consumption.
- different gas species (air or hydrogen) have a significant impact on the adsorption capacity resulting from different adsorption kinetics (faster diffusion of water molecules result in higher adsorption capacity).

The TSA model predicts the performance well. The influence of process parameters like gas species, temperature, water content and feed flow rate is correctly predicted.

The work performed has indicated a significant influence of hydrogen as carrier gas on the adsorption capacity and adsorption time allowing us to design specific TSA systems for drying moist hydrogen gas flows. The works carried out also allowed applicability of the adsorption model for drying gases with high water loading, compared to exisiting models. The TSA model is evolved beyond existing models for drying air.