CYCLIC TESTING PROGRAM DEFINITION

HYPSTER PROJECT

Deliverable 1.3

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V1	Storengy	30/11/2021	First version with inputs from D1.1
V2	Storengy	28/02/2022	Implemented changes after WP internal discussion
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1. INTRODUCTION

The document was written for the Work Package 1 of the HyPSTER project in the Task 1.2. It correspond to the Deliverable 1.3: "Cyclic testing program definition". The principle is to synthetize the work of the Task 1.1 "Analysis of hydrogen consumption profiles and customer perspectives" which studied :

- features of hydrogen production from renewables (PV, Wind and hydraulic energy) and,
- customer perspectives and storage utilization profiles in the area of the pilot,

This report thengoes on to define hydrogen storage experimental cycles to use in the EZ53 cavern during the pilot phase. These experimental cycles should cover the different storage needs identified to demonstrate the ability of salt caverns to answer the energy storage problematic.

2. STORAGE NEEDS IDENTIFICATION

2.1. Hydrogen production

For the HyPSTER project, Element Energy[1] analysed the potential for renewable electricity production in the Etrez area and therefore the potential for renewable hydrogen production based on an assumed electrolysis capacity of 1MW. The conclusions of this analysis indicate that if we want to optimise the hydrogen production by electrolysis with a 1MW PEM electrolyser, we need to consider renewable energy installed capacity of around 20MW and preferably by combining different energies, namely solar photovoltaic, wind and hydroelectricity, known as "run of the river". All these energies are intermittent:

- For photovoltaics, a very marked day/night variation but also significant summer/winter seasonal variations,
- For wind power, essentially seasonal variations (low production in summer, high in winter)
- For hydro power, production is more continuous but with a rather marked seasonal variation spring/autumn.

It should be noted that these analyses integrate regional data, whether for sunshine, wind power or run-of-the-river hydroelectricity capacity in the Auvergne-Rhône-Alpes region.

2.2. Consumption

According to previous analysis work by Storengy[2] , the current consumption of renewable hydrogen in the Etrez area is almost zero. Nevertheless, many projects are being developed. Some are in the implementation phase, such as the Zero Emission Valley project managed by Hympulsion, which aims to offer hydrogen refuelling stations throughout the region, or the Dijon Métropole project, which plans to produce up to 11MW of hydrogen by electrolysis.

The different projects generally plan to produce locally and consume this hydrogen with a very low seasonal variability but possibly a marked day/night variability for the supply of a fleet of buses and/or refuse collection vehicles or the supply of service stations for light vehicles. In the same way, industrial uses of hydrogen (currently covered by grey hydrogen) have been identified in the region and correspond to continuous needs without seasonal or daily variability.

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[1] William Nock, Louis Day, Felicia Chang, 2021, *Deliverable 1.1: H_2 production and consumption profiles*, Element Energy, HyPSTER Project.

[2] Rostand N'Gameni, Gregoire Hévin, 2021, Deliverable 1.2 *Estimation of the need for H2 storage around Etrez,* Storengy, HyPSTER Project.

Two different types of need are therefore identified:

- a continuous need for customers who do not produce their hydrogen
- a support or back-up need for customers who produce a large part of their hydrogen but may face production interruptions, either for planned preventive maintenance (~10 days/year) or for unforeseen curative maintenance of their electrolysers (a few days/year).

These two profiles are very different. For the first a continuous production and supply must be considered and for the second, a supply by peak according to the production stoppages giving a very strong variability. Thus for the latter no demand most of the time and a strong need on a limited duration of a few days.

2.3. Production/Consumption balance: the need for storage

The interest of storage is precisely to be able to respond to these different variabilities, whether they are linked to production or consumption. On this basis, a sort of triple profile of use of the stored volume emerges:

- small daily variations (mobility uses, solar production, etc.) ;
- seasonal variations of greater amplitude (seasonal production, etc.);
- very occasional large-scale peaks (back-up requirements, etc.).

To cover these different profiles, it will be necessary to combine them as far as possible.

The objective of this note is to propose pressure cycles to test the cavity for these different possible uses. It should be noted that, being in an experimental phase, the aim is not to propose to reproduce a realistic future operation but to propose relevant tests to cover the needs of a future operation.

3. CONDITIONS OF THE PILOT EXPERIMENT IN EZ53

3.1. Principle of operation by brine compensation method

In the HyPSTER Project and its hydrogen storage cavern demonstrator, some surface facilities are planned around the EZ53 cavern wellhead to perform pressure cycling. The cavern will be partially filled hydrogen.

Two options were possible:

- Inject and withdraw hydrogen into the cavity at each pressure variation cycle; and
- Compress and decompress a constant amount of hydrogen in the cavity by injecting and withdrawing brine.

The first option requires a hydrogen surface storage of an equivalent amount of hydrogen to be cycled and a high pressure hydrogen compressor. The second option allows for surface facilities only to handle brine and at lower pressure levels at the surface (but equivalent pressures in the cavern due to the weight of a brine column in the borehole casing). For safety and budgetary reasons, the second option was preferred.

The principle of the experiment is described in the Figure 1. The necessary surface facilities are shown in Figure 2. The experiment can be considered to be more similar to brine compensation method of operation than to a conventional compression-expansion operation for gas storage. Brine compensation method has the advantage of not requiring cushion gas but the disadvantage of having to deal with saturated brine with the associated risks of crystallisation and plugging of pipes (to avoid these problems, a dilution water system was added, as shown in the diagram of the Figure 2). In the case of the experiment planned in HyPSTER, the consequence is that at each cycle, a slight surplus of brine will be generated due to this dilution water. This surplus will have to be regularly evacuated to the site.

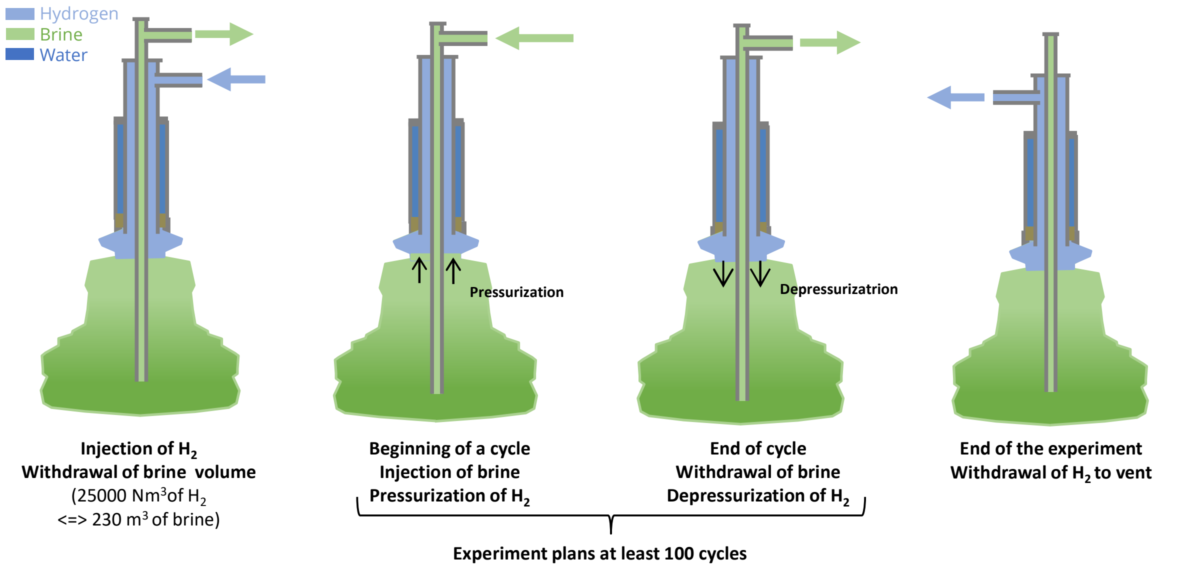

Figure 1: Principle of the cavity pressure cycles performed during the pilot experiment. After the hydrogen is placed in the cavity, about 100 compression-expansion cycles will be performed before the final withdrawal of the hydrogen.

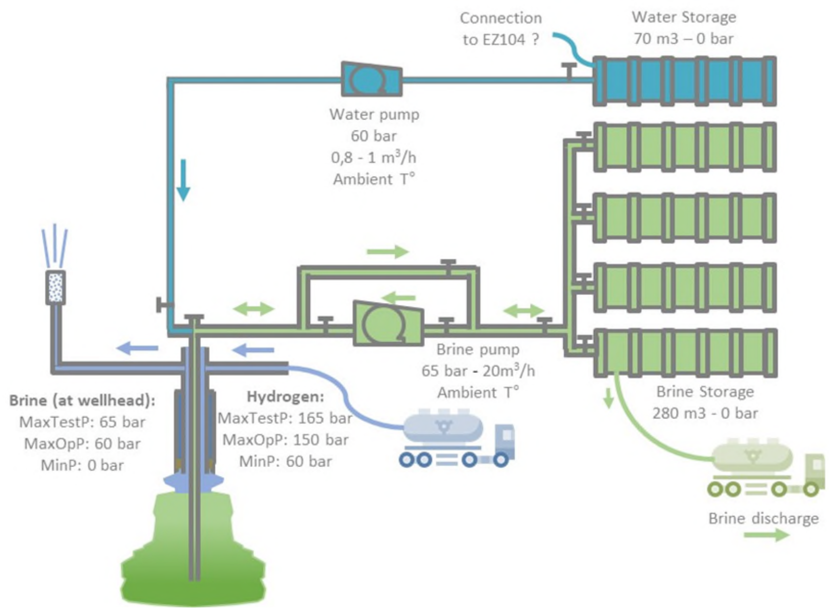

Figure 2: Schematic diagram of surface facilities

3.2. Maximum and minimum test pressures

The maximum operating pressure (P_{max}) of a gas storage cavern is generally set at a gradient of 0.18 bar/m (standard operating gradient for gas caverns) at the last cemented casing shoe. Applied to the EZ53 cavern with a last cemented casing shoe depth of 841.73m, this gives a P_{max} of 151.5 bar (= 841.73 x 0.18).

The minimum operating pressure (P_{min}) is set independently of the depth. Initially, one could consider the P_{min} of the administrative authorisation for all the Etrez cavities, which is set at 60 bar. However, in the planned configuration of EZ53, when the brine is drawn off until it reaches zero pressure at the wellhead, this will correspond to a pressure of 109.5 bar at the interface at 930 m due to the weight of the brine column.

The pressure difference between P_{max} and P_{min} is therefore 42 bar (=151.5 - 109.5).

To vary the pressure from 109.5 to 151.5 bar, the volume of brine to be injected into the cavity is around 80 m^3. Considering that it is reasonable not to vary the pressure by more than 10 bar/h, the brine pump was sized to obtain a flow rate of 20 m^3/h. This allows a complete cycle to be completed in 8 hours (4 hours of injection and 4 hours of extraction), i.e. a complete cycle to be completed in one day (or even 3 complete cycles per day in automatic mode if necessary).

Finally, to explore pressures lower than 109 bar, two techniques are planned for the final withdrawal of hydrogen.

- The first will consist of finishing the last cycle at P_{max} by injecting not brine but water (about 10m^3). Thus the whole column will be made of water with a density of 1 instead of 1.2 for brine. The weight of the corresponding column will be 91 bar instead of 109.5 bar. This gives a pressure difference of 60 bar (= 151 - 91 bar) with the same level of pressure control.

- Finally, in order to go even lower, it is envisaged to extend the withdrawal of hydrogen below 91 bar. As a result, the pressure on the water side will become lower than 0 (with vaporisation phenomena of the water in the sub-atmosphere to be expected in the upper part of the well). It should also be considered that the static pressure information at the top of the water column will be lost. It is considered reasonable to go down to about 80 bar before reinjecting brine into the well, 80 bar corresponding to the minimum operational pressure of the Etrez cavities today. The pressure difference between P_{max} and P_{min} would therefore be 70 bar.

It should be noted that both techniques can only be used for the last hydrogen withdrawal, when it is possible to inject and keep water in the well during hydrogen withdrawal.

It should be noted that all the pressure values given here are estimates calculated by neglecting pressure losses (static calculation) and by considering constant temperature and cavity volume conditions. While it does not appear necessary at this stage to consider these phenomena in order to define and make recommendations for a cycling programme, it will nevertheless be useful to refine these calculations for the follow-up of the real experiment.

4. RECOMMENDATIONS FOR CYCLING TESTS

As mentioned earlier, the use of hydrogen storage, as it is emerging, is based initially on a superposition of small daily variations and large seasonal variations.

To test this configuration, it is recommended that, after a period of stabilisation at high pressure following the introduction of hydrogen, :

- Initially, carry out cycles with an amplitude of a few bars representing 10% of the maximum amplitude. Two of these "small" cycles can be performed per day for 7 days.
- achieve a pressure drop of 100% of the possible amplitude in 7 days without stopping the "small" cycles.
- remain at minimum pressure for 7 days in order to observe the stabilisation of the system, in particular thermally, and check the behaviour of the hydrogen cavity. Then restart the "small" cycles at low pressure for 7 days.
- increase to the maximum pressure in 7 days without stopping the "small" cycles.

The return to maximum pressure marks the end of the first "major" cycle in 6 weeks. This first experiment will allow the verification of the operation of the brine injection-withdrawing system, the pressure monitoring system and the interface position variations. It will also allow to check the influence of potential thermal effects.

Depending on the results, it is recommended that this system of large and small cycles be repeated twice. As the planning objective is to carry out the entire experiment in approximately 3 months, it is recommended to try to limit the duration of a large cycle to 5 weeks, by favouring the most relevant stages identified during the first large cycle.

The third anticipated use of storage is for peaks. Beyond the representative aspect of such an operation and based on the first part of the experiment, it is recommended to carry out cycles P_{min} - P_{max} using all the injection-withdrawing possibilities. This will enable a cycle to be carried out in 12 hours (6 hours of injection/6 hours of withdrawal). It is therefore proposed to carry out at least 10 cycles over 100% of the pressure amplitude. These cycles are clearly excessive and are not representative of a realistic operation whatever the use, but they are relevant in the context of tests. It should be noted that the well equipment suppliers have expressed the wish to have more of these increasing cycles. This can only be done if the duration of the other cycles is reduced in the light of experience (fewer short cycles? shorter stand-by periods?).

The final stage of testing is to withdraw the hydrogen and send it to the vent. As mentioned in the previous paragraph, to explore pressures lower than 110 bar, the central column of the well will be filled with water (which will increase the head pressure on the water side by about 18 bar). Then the hydrogen will be drawn off to reach 0 bar on the water side, which corresponds to about 92 bar on the hydrogen side. Finally, the hydrogen withdrawal is extended to 80 bar (static). This operation is representative of the emptying of a cavity as in the case of cold peaks such as can be experienced in natural gas storage cavities. The hydrogen withdrawal can be carried out in 7 days, which corresponds to a depressurisation rate of around 0.4 bar/h, which is slow (the major cycles will be carried out at around 10 bar/h, which is a maximum standard in the profession) but fast at the same time compared to the duration of the complete withdrawal P_{max} - P_{min} of a classic cavity, which is of about three weeks to a month.

The wellhead pressure changes on the brine side and on the hydrogen side during all of the above tests are shown in the Figure 3.

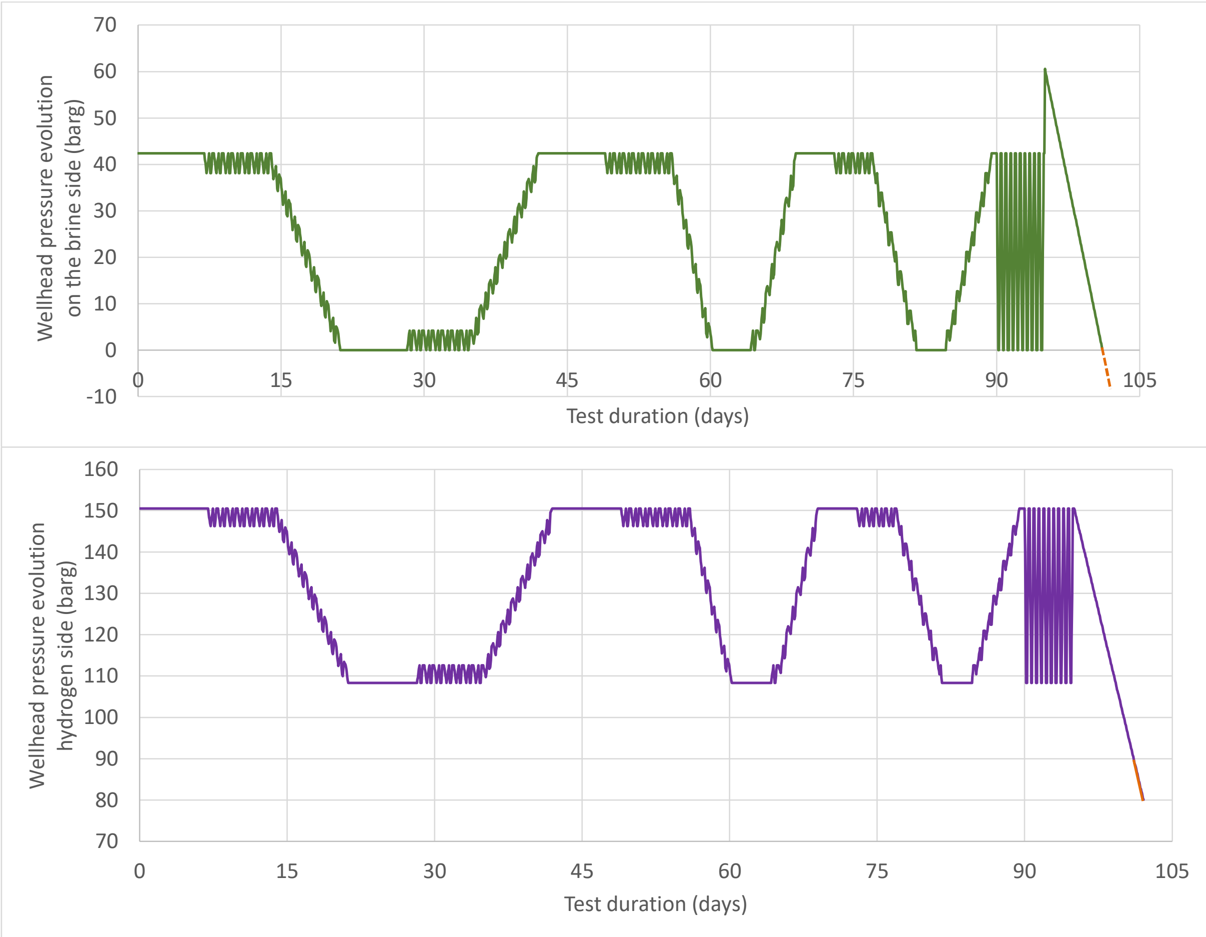

Figure 3 Evolution of the pressure on the brine side at the top (green curve) and **on the** hydrogen side at the bottom (purple curve). The orange part of the curves corresponds to the period when the pressure is sub-atmospheric on the brine side.

5. CONCLUSION

This document proposes cycling pressure tests to be performed in the EZ53 cavern partially filled with hydrogen. These definitions are based on the analysis of the WP1 of the HyPSTER project which identify the possibilities for local renewable hydrogen production in relation to renewable electricity production as well as renewable hydrogen consumption profiles in the Etrez region. On this basis, a triple storage use profile was identified:

- small daily variations (mobility uses, solar production, etc.);
- seasonal variations of greater amplitude (seasonal production, etc.);
- very occasional large-scale peaks (back-up requirements, etc.).

The proposed cycling tests also take into account the real conditions of the planned experiment in the EZ53 cavity. Indeed, it is planned to create cycles of hydrogen pressure variations in the cavity by brine compensation method, which somewhat limits the range of pressure explored.

The proposed recommendations nevertheless make it possible to test a superposition of daily cycles of small amplitude and monthly cycles of larger amplitude, as well as to plan major cycles of large amplitude over very short periods. Finally, a final withdrawal of hydrogen will complete the experiment by a decrease of pressure until 80 bar as minimum possible pressure.

6. ANNEX

ANNEX 1 – ELECTRONIC FILLING IDENTIFER

Document Name and version	<D1.3 Cyclic Testing Program Definition – Final version >
Description	< This report aims to define hydrogen storage experimental cycles to use in the EZ53 cavern during the pilot phase. >
Location	<'WP1 – Definition of inputs and output specs & identification of the different cyclic tests to conduct Coordination' > 'D1.3' >
Filing date	<16/05/2022>

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