Large scale energy storage

CryoHub

Developing Cryogenic Energy Storage at Refrigerated Warehouses as an Interactive Hub to Integrate Renewable Energy in Industrial Food Refrigeration and to Enhance Power Grid Sustainability

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691761.

Deliverable D11-2
CryoHub tested

Deliverable Information

Dissemination	: Public
Nature	: Demo
Contractual Delivery Date	: 30.11.2020
Actual Delivery Date	: 29.03.2021

Scientific coordinator : Prof. J.Evans
London South Bank University, UK
e-mail : j.a.evans@lsbu.ac.uk

Document Information

Project	: CryoHub
Document	: D11-2 CryoHub tested
Filename	: D11-2 CryoHub tested S1.docx
Last saved on	: 29/03/2021 17:06 by Tim BROWN and Jacques BERTRAND

Authorship and Review

	Name (Organisation)	Approval Date
Written by	Tim BROWN (LSBU) and Alan FOSTER (LSBU)	29/03/2021
For review by	Judith EVANS (LSBU)	29/03/2021

Release Details

Release	Date	Comments
Draft 01	29/03/2021	First draft
Release 01	29/03/2021	Reviewed by Judith EVANS
Submitted	29/03/2021	Submitted

Distribution List

- On the project Portal
- On the CryoHub Intranet (http://CryoHub.psutec.com/)

Table of Contents

1. Executive summary 4
2. Site Acceptance Test 5
3. Preliminary running of the demonstrator 9
4. Steady state running of the demonstrator 10
5. Initial test results 10
6. Conclusion 14

1. Executive summary

CRYOHUB is a European collaborative project that aims to develop cryogenic energy storage using renewable energy to refrigerate food storage warehouses and to enhance power grid sustainability.

In its entirety, the CryoHub concept would contain the following subsystems:

- Air liquefaction for storage of excess renewable energy or when demand is low
- LA (liquid air) storage in a pressurized cryogenic vessel
- Discharge of the LA for warehouse refrigeration and energy recovery when demand is high.

The CryoHub project includes design, build and testing of a demonstrator system which excludes the expensive and proven technology related to liquefaction, but which includes thermal storage, warehouse cooling and power generation from the discharged cryogen.

This deliverable details the Site Acceptance Test, preliminary running experiences and initial testing results from the demonstrator. The demonstrator will be used for extended testing to be reported in D11-3 and in the final project reports.

2. Site Acceptance Test

Following the transfer of the main CryoHub demonstrator skid to the Frigologix refrigerated warehouse site at Lommel in Belgium, additional components such as the thermal store and warehouse heat exchangers were integrated as detailed in deliverable D11-1, and the liquid nitrogen supply vessel was connected.

A Site Acceptance Test (SAT) was carried out by Dohmeyer. This is a physical and electrical inspection to check that components function as expected and that the assembly and integration is sound. The SAT document is shown below, signed off on behalf of the consortium by Frigologix's representative.

SITE ACCEPTANCE TEST DOH-3383

Status
Document issued for SAT

DOHMEYER
CRYOGENIC • FREEZING • PRECISION

Document number	202 012 222 219
Prepared by	Marlena Kupiec
Date	22.12.2020
Version	v 1.23

DURING FAT, PLEASE FILL FORM BEGINNING PAGE 2

General information

Constructor	Dohmeyer Construction Sp. z o.o. ul. Wojska Polskiego 3 39-300 Mielec Poland
Purchaser	London South Bank University Churchill Building Langford, Bristol, BS40 5DU UK
Equipment type	DOH-3383
Type	Cryohub Demonstrator
Construction	SKID + storage vessel

Identification plate

Type	Engraved
Place of label	Electrical cabinet
Serial Number	202 012 103 383
Construction year	2020
Weight	17000 kg
Cooling Medium	NITROGEN
Pressure range	1 - 16 bar
Maximum Pressure	20 bar
Power consumption	100kW
Electrical connection	3 x 400 VAC + N + Pe, 50 Hz
Type of Approval	2006/42/CE

OK = conform to specifications
NOK = not conform to specifications
NA = not applicable

Questions	Results of tests	OK	NA	NOK	Remarks
Machine construction					
Were sharp corners removed?		+			
Is the surface looking good?		+			
What are the weldings?		+			
Is there any penetration in the welds?		+			
What is the finishing of the installation?	Small paint damages to be repared	+			
Is the piping mounted properly?		+			
Is the CE label quality good?		+			
Electrical cabinet					
What is the power supply (voltage, neutral, XXHz)?	3x400VAC+ N + PE	+			
Is the electrical cabinet ventilation working correctly?		+			
Are all paramteres correct in frequency inverters?		+			
Is/are temperature controller/controllers working corectly?		+			
Is there door protective grounding?		+			
Are door locks working correctly?		+			
Is the e-cabinet seal tight?		+			
Are led lamps working correctly?		+			
Do all buttons have label?		+			
Are cables fixed correctly? (Check it by pulling a random cable)		+			
Is the key attached?		+			
Field elements					
Are there all emergency buttons? How many?	2	+			
Are all emergency buttons working correctly?		+			
Is the signalisation working correctly?		+			
Are the all PT100?		+			
Are all sensors working correctly?		+			
Are all safety valves wokring correctly?		+			
Is flowmeter working correctly?	To be checked during cold test in January	+			
Are cameras installed properly		+			

Questions	Results of tests	OK	NA	NOK	Remarks
Pneumatics					
Is the filter installed?		+			
Is the drain in place?		+			
Are valves working correctly?		+			
Are pneumatic hoses without damage or leak?		+			
Is the electrical connection of valves correctly?		+			
Is the manometer working correctly?		+			
Cryogenic elements					
Are valves DN80 working correctly?		+			
Are valves DN40 / DN25 working correctly?		+			
Is the connection tight?		+			
Is there any leak?		+			
is the liquid nitrogen flexible connected?		+			
is the gas return flexible connected?		+			
Is liquid nitrogen tank filled?		+			
Motors					
Are recirculation fans working correctly?	only manual test done without flow	+			
Are turbines working corectly	only manual test done without flow	+			

Safety items

Does the main switch disconnect all power?		+			
Is the main switch easy to reach?		+			
Are there any leaks at cryogenics components?	To be checked during test in January	+			

Functional test

Manual opening of all the valves		+			
Manual run of recirculation fans		+			
Manual run of cryogenic pump		+			
Manual run of turbines		+			
Checking readouts from the temperature sensors		+			
Checking readouts from the pressure sensors		+			

Remarks/actions for future

Functional test was perform.
Air Liquide needs to deliver pressure and level sensor - to be connected
HX 1A and 1B needs to be electrically cabled as the connection box is missing.
Pressure sensors for storage tank needs to be delivered and installed by Cener
Ethernet connection to be established to allow remote access
Recirculation fan needs to be serviced
More tests needs to be done after new year
Commissioning and test with cooling medium to be continued

Hereby, customer, I confirm the acceptance of the equipment as described above.

Date: 22.12.2020

In name of LSBU:
Henk Foole (Frigologix)

For Dohmeyer
Tomasz Kucwaj

3. Preliminary running of the demonstrator

Initial testing of the demonstrator performance was then carried out, using a combination of remote control and datalogging via software developed by CENER and Dohmeyer, with remote operational input from LSBU and on-site physical monitoring and adjustments by Dohmeyer personnel.
The fans used to recirculate nitrogen between the thermal store and warehouse heat exchangers (HXs) burnt out. This was caused by fragments of glass, which must have come from damaged beads from the thermal store. The cost and timescale to fix the fans meant that it was not possible to use the fans and thus not discharge the thermal store for the following tests.
Problems were found with the build-up in pressure in the system caused by nitrogen warming due to heat gain from the surrounding environment between tests. The system was not built with an adequate venting control. This meant that nitrogen needed to be vented before a test could start and the only place to do this was through the turbines. However, venting through turbines which were not in an operational condition (generators need somewhere to discharge the power generated) caused the turbine inverters to burn out.

A number of other issues were identified, and the following list of rectifications was made.

- Replacement inverter and fuses fitted to the power turbine set.
- Filter fitted before turbines in case fragments of glass reached that far.
- Vent valve fitted in line to allow the system to be vented without damaging the inverters.
- Temperature sensor moved from thermal store line to allow measurements after LIN pump.
- Several sensors appeared to give false readings. For example, temperature sensor T18 did not change when valve condition changed, it appeared to give the temperature expected for a closed valve even when open. It was later found that the ammonia sensors were not designed for outside conditions and these were replaced for more suitable sensors.
- An ambient (outside) temperature was added. This sensor was later used as a replacement for another malfunctioning sensor.
- Pressure sensors on the thermal store had not been fitted and were found to be still at the store supplier’s factory. The sensors were then delivered with thread connections missing, so connectors were prepared, and the sensors installed.
- The initial test of the LIN pump registered a fault status. Operation was checked and error did not recur.
- Bearing temperatures for turbines were not being recorded and monitored by the main control system, only by the turbine supplier’s control panel. Remote access to this information was requested.
- Defrost termination temperature sensors and ammonia condensing pressure control were fitted and connected to the main control system.

This allowed the temperature of the inter-stage re-heat to be increased, as it was too low in the cold winter conditions.

- Minimum pump speed was changed to zero in the control program to better control pressure.
- Graphics in the Ammonia Control screen were corrected – for example HX2 was shown as a duplicate of HX3.

4. Steady state running of the demonstrator

The demonstrator was run for several hours until steady state conditions were achieved. The following issues were evident:

- T1 probe was not positioned in liquid nitrogen, so it did not provide a sensible result. An alternative sensor on the pump was used instead.
- Defrosting was extremely difficult but necessary, with heavy icing after only a few hours. Running the defrost without fans meant that the defrost control probe could still be very cold but air temperature probes very warm. There was thus a need to keep turning fans on and off to spread the heat. Work to check the defrost method is continuing, with manual validation at the plant to check the condition of the exchangers to confirm when they are properly defrosted.
- The pump was not able to pump to the correct pressure at the required flow rate. It was found that allowing the LIN vessel to reach a higher pressure and bypassing the pump was the best solution and provided no obvious drawbacks.
- It was not possible to modify operating parameters during a test. The control software was modified to allow parameters to be altered during a test.

5. Initial test results

Extended testing of the demonstrator will be reported in deliverable D11-3 and the final project reports but results from initial testing of the demonstrator have been analysed.
In ‘warehouse cooling only mode’ without charging the thermal store, the demonstrator produced 129 kW of cooling to the cold store warehouse and at the same time 45 kW of electrical energy generation from the turbines. This required the expansion of 0.42 kg/s of liquid nitrogen at a pressure of 16.3 bara at the LIN vessel. Calculated turbine efficiencies were lower than expected during the test, averaging just under 60% instead of the design values which averaged 78%.
From the analysis of turbine outlet temperatures versus the outlet flow conditions provided by the manufacturer it appeared there was a significant discrepancy that could not be explained by the thermal inertia of the pipework or the generator cooling system configuration. Isentropic efficiencies calculated using the manufacturer’s data are in the region of 74-80%, while those measured from the

flow temperature ranges between 52-64%. The change in temperature due to the cooling system (~5K) would account for 5% of that difference, but not more.
There is an upward trend in efficiency as the pressure decreases through the expansion stages. This indicates that the rotational speed is not "matched" to the specific speed needed for an efficient expansion. This should have been optimized on each stage, but this was not done. There could be scope to change the RPMs on each stage and find an optimum.
In further testing, it would be good to run the expanders at maximum rotational speed (22k RPM) and at 20k RPM to find out whether the specific speed increase improves the isentropic efficiencies or if the windage losses offset any gain.
Finally, there would be scope to increase the turbine inlet temperature to 50°C with little detriment to the cooling system. This will increase power output all else being equal, but it might decrease the isentropic efficiency if the turbine efficiency characteristic moves further away from design point.
The thermal store was then charged with LIN, but temperature measurements recorded during charging were not logical. Further work is ongoing to check that sensors are correctly positioned and to try to understand the flow within the thermal store.
Measurements were conducted on the thermal performance of the thermal store after temperatures equalised after charging. The temperature increased linearly from -46.9 to -38.2°C in a period of 165 h, giving a temperature rise of 0.0524 K/h or 1.26 K/day. Over this small temperature difference, the specific heat (Cp) relationship with temperature is linear and thus it is accurate to use a mean specific heat for both the steel (445 J/kg.K) and glass beads (614 J/kg.K). This gives the thermal mass of the thermal store as 6.35 MJ/K. Over the recorded time period this leads to a heat loss of 93.3 W. Based on a surface area on the outside of the store of 23.3 m^2, this gives a heat transfer U value of 94.1 mW/m^2K.
It was not possible to discharge the thermal store as the fans are damaged and unable to be replaced during the project.
As described above the first tests were done with a mixture of remote control by LSBU via the control system developed by CENER and Dohmeyer and physical interventions on site by Dohmeyer personnel. The control system and the demonstrator itself are now capable of fully remote operation, and a selection of the control screens are shown below.

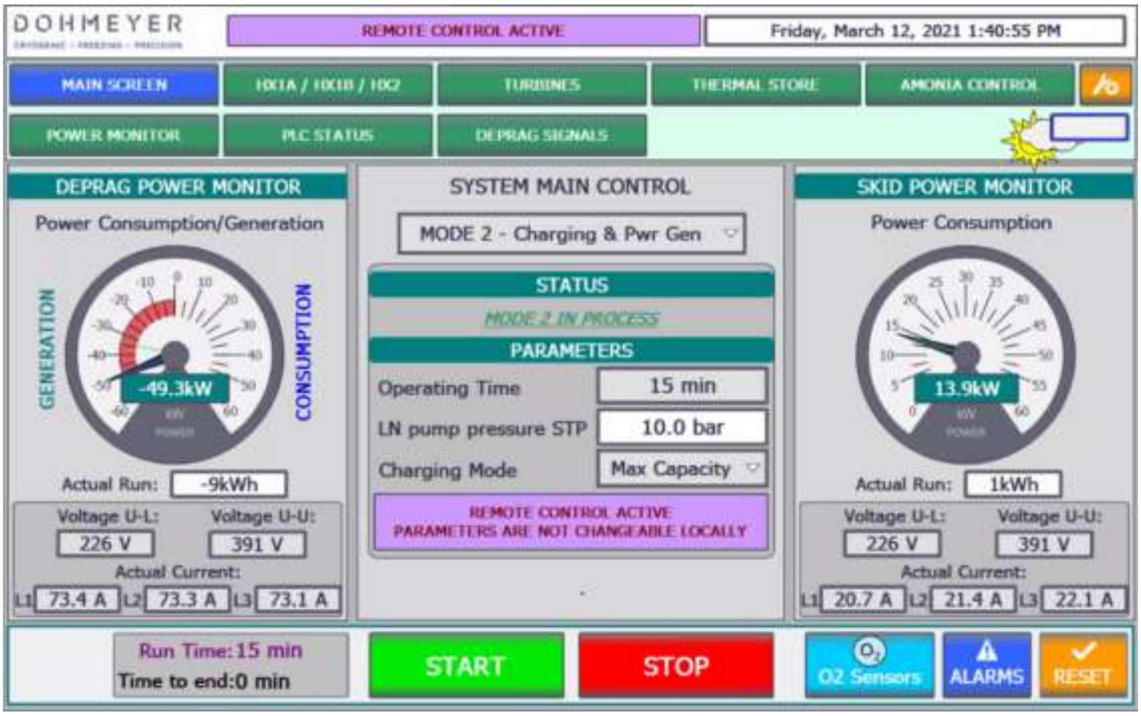

Figure 1. The main control screen, showing operation in generation mode.

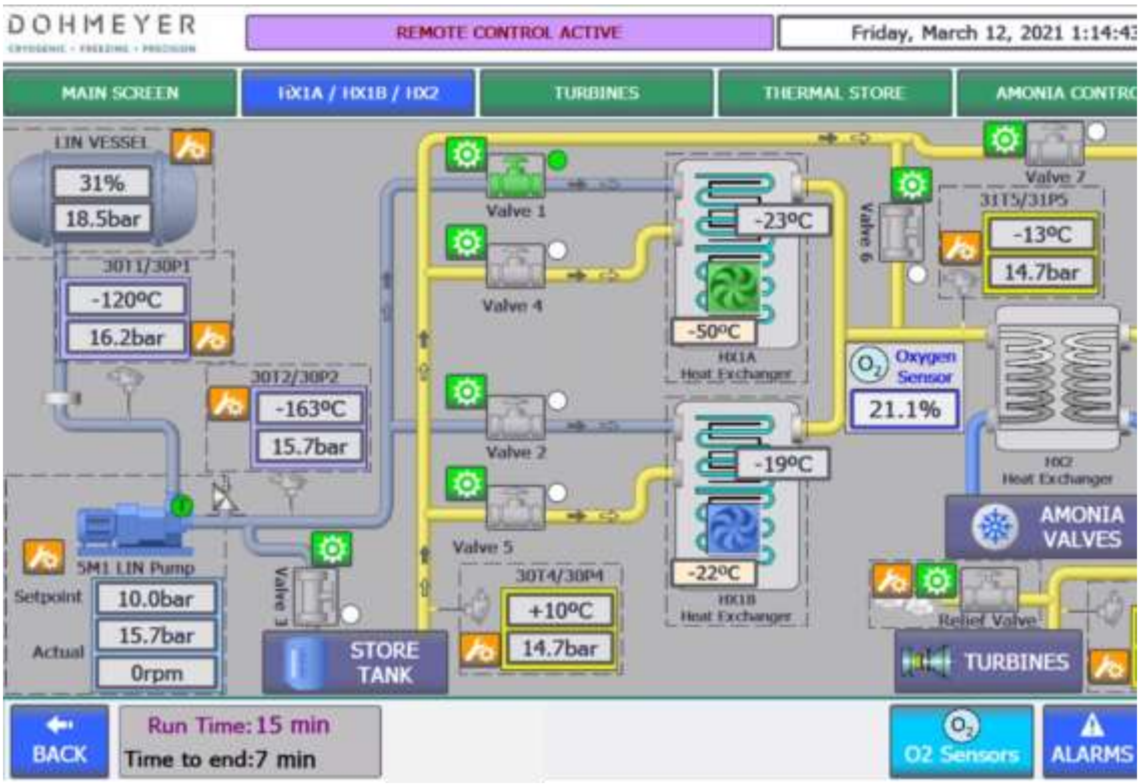

Figure 2. Temperatures and pressures in the nitrogen system.

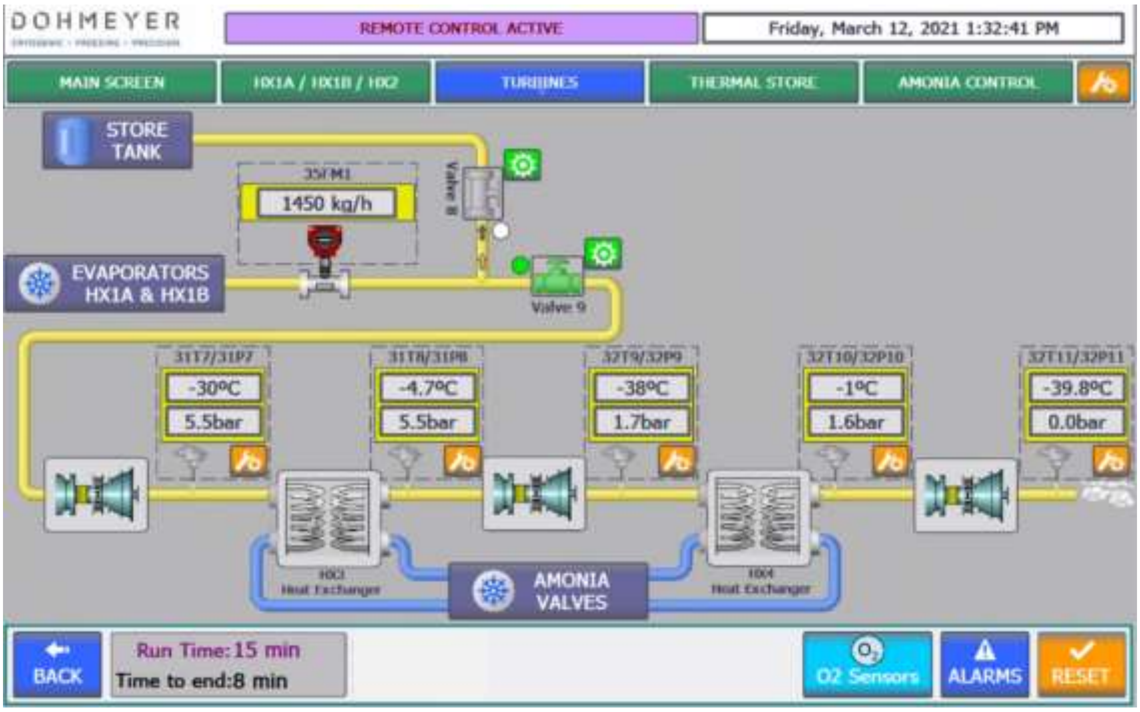

Figure 3. Operating parameters of the three turbines.

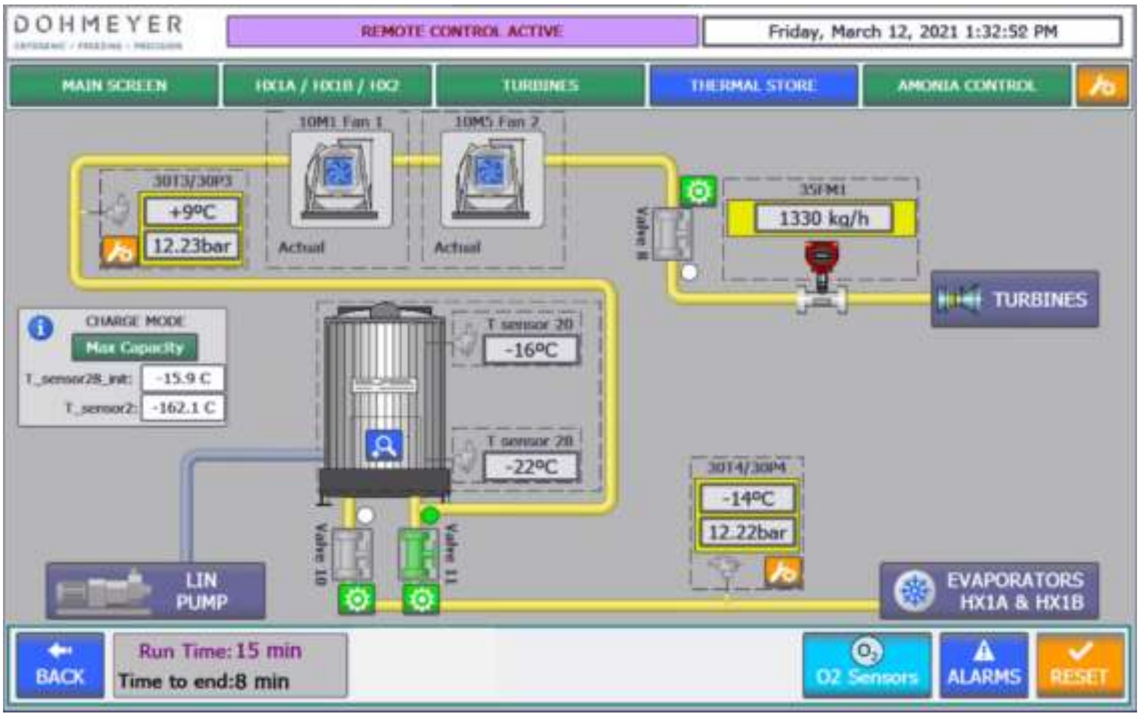

Figure 4. Thermal store sub-screen.

6. Conclusion

The CryoHub demonstrator has been installed at Frigologix and tested for component operation and system control. A number of operational issues have been resolved and the demonstrator is operating successfully using remote controlled operation. Initial results are briefly described in this report, and extended testing will follow and be reported in deliverable D11-3 and the final project reports.