PAPER ID: 0011
DOI: 10.18462/iir.cryo.2019.0011

Cold Storage Solutions for a Liquid Air Energy Storage System

Gregor TROMMLER[(a)], Martin KLUPSCH[(a)], Detlef EGGERS[(b)], Philipp BOBSIN[(b)], Christian WENDT[(c)], Niklas BOHNE[(d)]

[(a)] Institut für Luft- und Kältetechnik gemeinnützige Gesellschaft mbH
Dresden, 01309, Germany, gregor.trommler@ilkdresden.de, martin.klupsch@ilkdresden.de
[(b)] RST Rostock System-Technik GmbH
Rostock, 18119, Germany, d.eggers@rst-rostock.de, p.bobsin@rst-rostock.de
[(c)] Ariane Group, Bremen, 28199, Germany, christiandr.wendt@ariane.group
[(d)] Universität Bremen, Bremen, 28199, Germany

ABSTRACT

The switch to renewable energies requires new ideas and concepts, which the ILK Dresden has intensively addressed in recent years. Explicitly, an energy storage system based on Liquid Air Energy Storage (LAES) was developed as part of a publicly funded project. This energy storage is based to a large extent on the principle of liquefied air, in which the processes for liquefaction and regasification are adapted to the requirements of the power storage. Integral parts of the liquid air storage system are various cold storages. The different cold storage tanks must be precisely coordinated with one another in order to generate stable operating parameters regarding the efficiency of the overall process. The publication explains and describes constructive aspects and challenges in the implementation of these cold storages and in their entirety. Results of the material selection as well as thermal simulations and calculations will be introduced. Experimental results of the cold storage in the composite of the entire energy storage are presented as their benefits for similar facilities.

The work was partially supported by the Federal Ministry of Education and Research (03WKCR5C) on the basis of a decision of the German Bundestag.

Keywords: Energy storage, Energy recovery, Liquid air, Efficiency, Liquefier, Cold storage.

1. INTRODUCTION

With the further expansion of renewable energy plants connected to the electrical power grid the demand for electrical energy storage systems will increase in the next years. Current developments in this application range from hydroelectric power plants across power-to-gas or -liquids onward to batteries and capacitors. All of these techniques have their own problems and limitations. We assume that an adapted air liquefaction and regasification process with various loss reduction measures will lead to an electrical energy system that is technically so efficient and cost-effective that it will attract attention in comparison with alternative storage technologies.

A description of the publicly funded joint project "OWS – Offshore Wind Solution" with its contents and goals was presented by Großmann (2017) at the 14th Cryogenics. The project was mainly concerned with the consideration and evaluation of components to increase the efficiency of liquid air energy storage systems. The project ended in October 2018. In the following the decisively project results are described – the efficient energy recovery system via internal cold storages in a Liquid Air Energy Storage System – with the basic considerations, the theoretical calculations and the practical tests.

2. MAIN SECTION

2.1. Liquid Air Energy Storage

Within several thermodynamic calculations of the LAES under consideration of different efficiency-increasing components, it has been shown that a significant increase in efficiency can only be achieved by interconnecting several components within the LAES. These calculations have shown that the use of the cooling energy released during regasification for pre-cooling during liquefaction brings the decisive efficiency gain. The use of this cold is currently already state of the art (for example: company "Highview Power"), but the efficiency of its use can be significantly increased.

A more efficient use of this cold is achieved by splitting up the usable temperature range taking into account reasonably available storage materials and considering the operating modes of storage, standing time and discharge. A useful temperature range division into three sections was shown here. The ILK Dresden cooperated within the project content cold storage design and performance for use in a LAES with the company "RST Rostock System-Technik GmbH", the company "Ariane Group" and the University of Bremen. The worked out process principle of a liquid air energy storage with three cold storage systems is shown in Figure 1.

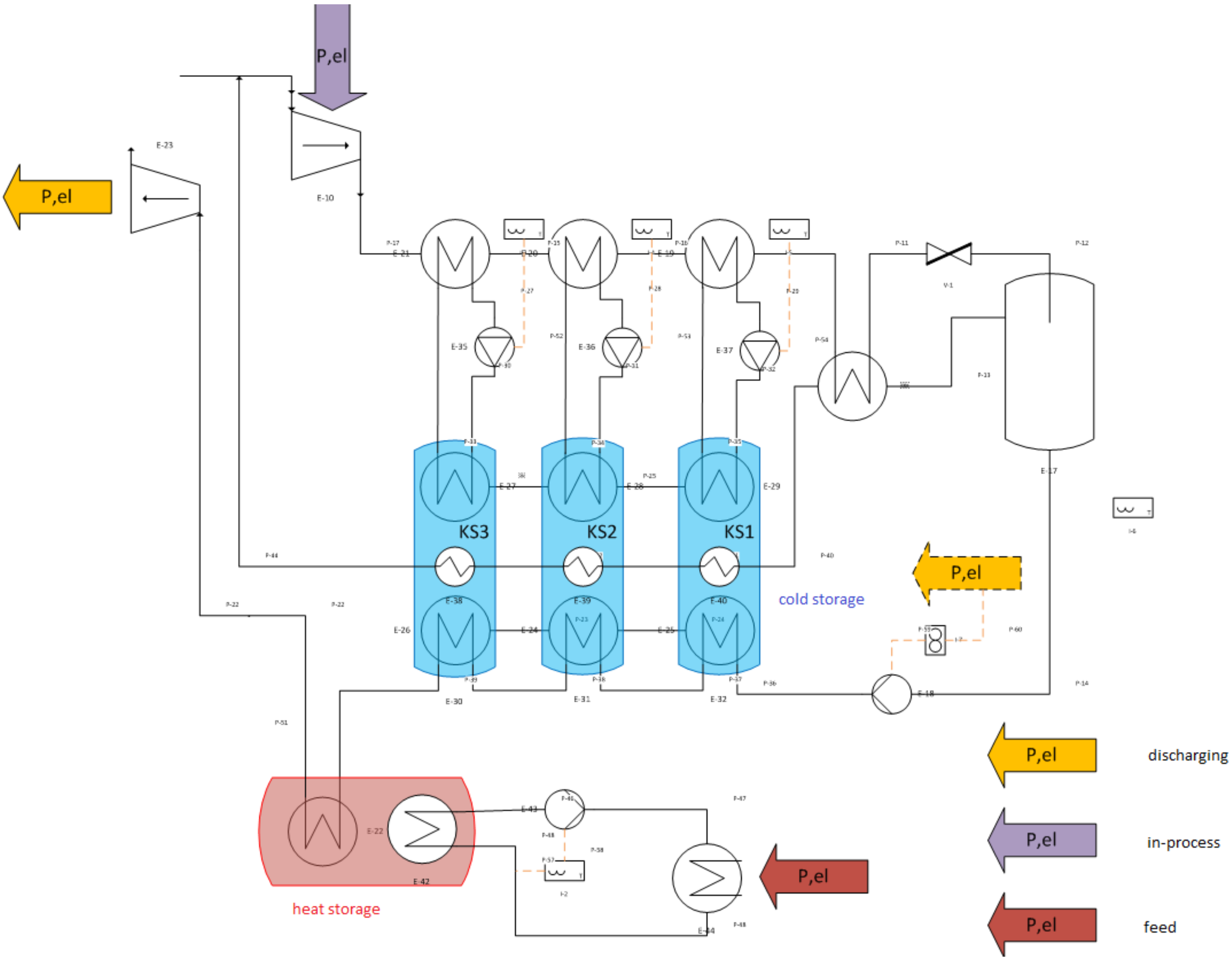

Figure 1: Scheme of the Liquid Air Energy Storage process with three cold storages

The calculations have shown that the use of three cold storages allows the most efficient use of the cold from the regasification process in the liquefaction process of the LAES over the entire temperature range during the dynamic operation of the LAES. For a LAES with these three cold storages and an additional heat storage, an efficiency of more than 55 % is achieved.

2.2. Cold Storage

An extensive candidate evaluation for the cold storage 1 (KS 1) and 2 (KS 2) for the categories technology, costs, risk and marketing resulted in the candidate type, which resulted in the maximum value in the sum of the criteria depending on a weighting. These storage types are combined systems consisting of latent and sensitive storage material adapted to the respective operating temperatures.

In the further work the focus of the analysis was set on the cold storage 2. It should operate in the temperature range of –140 °C and –60 °C and uses ethanol as a PCM, filled in capsules, and gravel to store the cold energy. This storage was analysed and compared to a same sized gravel-only cold store. For both cold storage configurations, an operating scenario was simulated with ANSYS Fluent, which consisted of loading, holding time and unloading. During the simulations, temperatures and heat flows were recorded into and out of the system. These data were used to evaluate configuration 1 (ethanol capsules and gravel) and configuration 2 (gravel). Figure 2 shows the temperature fields of the two cold storage configurations 1 (left) and 2 (right), at the end of each simulation.

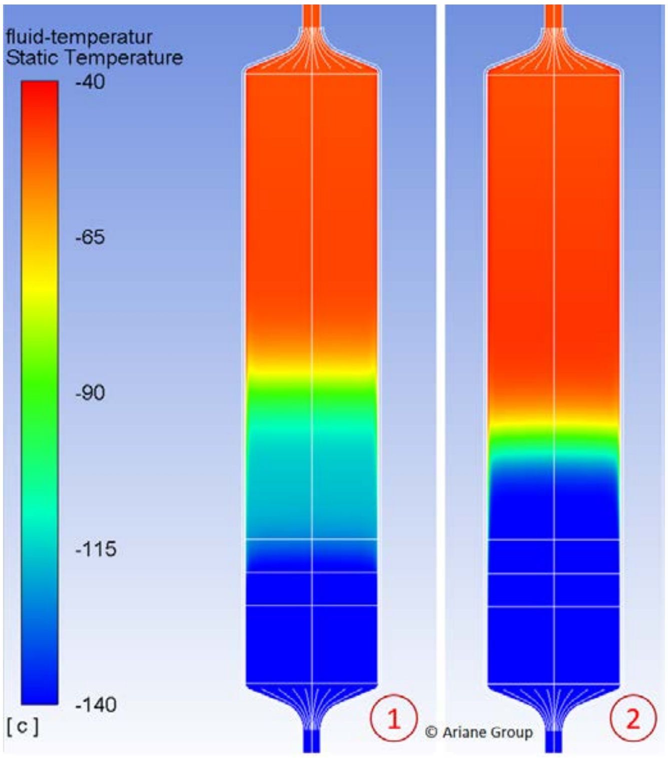

Figure 2: Temperature stratification of the fluid (left: configuration 1 - ethanol capsules and gravel; right: configuration 2: gravel-only). Simulation in ANSYS Fluent. Steady state condition. End of loading.

The results show, that the cold store with 18.2 % of ethanol capsules (2 m height) and 81.8 % (9 m height) of gravel achieves a 2.1 % higher efficiency than the gravel-only cold store. Additionally, it is able to provide an air temperature of below –100 °C during 95.2 % of the discharging time, compared to the gravel-only cold store, which only fulfils this request during 73.9 % of this time.

In addition, functional tests of two cold storage configurations with regard to discharge were carried out at a scaled cold storage. The two configurations are different in the composition of the storage medium (75% gravel and 25% ethanol capsules and 100% gravel). The test setup consists of the components: cold storage, fan, dehumidifier, measurement sensors and liquid nitrogen cooling. The temperatures in the cold store were measured during the tests. Figure 3 shows the test rig set up for this purpose with its assemblies.

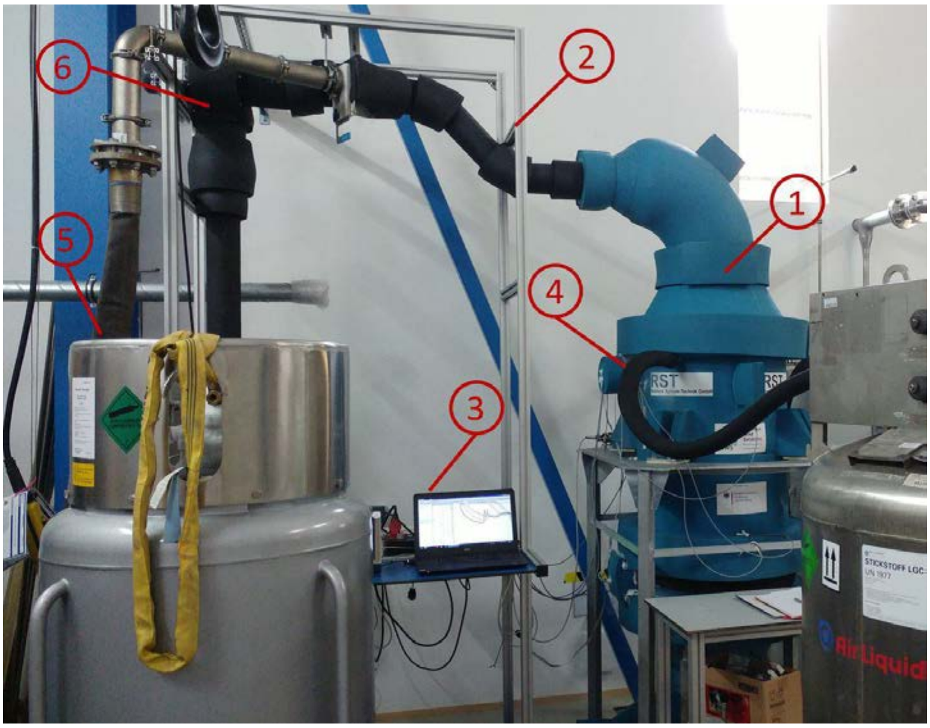

Figure 3: Picture of the test rig: 1 – Cold storage, 2 – pipe system, 3 – measurement station, 4 – first liquid nitrogen supply, 5 – second liquid nitrogen supply, 6 – fan

The two function tests start with the cooling of the cold storage, the loading, via liquid nitrogen injection into the air stream. This is followed by the discharge with practically dry air provided by the dehumidifier. The procedure is the same for both configurations.

The results of the measurements show for both configurations good matches comparing with the simulated assumptions. Small differences can be caused by errors in the assumptions or in the test conditions. Further tests under optimized test conditions are still necessary in order to be able to make a clear statement about the accuracy of the test setup in comparison with the simulation model.

3. CONCLUSIONS

An innovative cold storage concept was developed to increase the efficiency of a liquid air energy storage system. Three cold storages were defined for the entire temperature range available by regasification. Using the example of cold storage 2 the thermodynamic properties were investigated and evaluated. The special feature of this concept is its storage medium, which consists of a latent and a sensitive material in the form of ethanol capsules and gravel. An optimum ratio of the ethanol and gravel content was determined with regard to economic and performance-specific requirements. Both gravel and the ethanol capsules are available separately in piles. The cold store was evaluated by comparing it with a cold store that was identical in design but whose storage medium consisted only of gravel. For both cold storage configurations, an operating scenario was simulated, which consisted of loading, holding time and unloading. The results show that the cold storage concept with the ethanol and gravel can achieve a better efficiency in comparison with the gravel-only cold storage. A further advantage resulting from the results is that the cold storage with gravel and ethanol capsules provides an air flow with a temperature below –100 °C over a longer period than the gravel cold storage. This allows the cold store with ethanol capsules to be used more efficiently in the LAES plant over a longer period of time. In addition to the simulation, practical functional tests were carried out. The temperature curves within a cold storage are measured during the discharge of two configurations. A repetition of the tests under improved test conditions would make a clear statement possible regarding the accuracy of the test setup in comparison with the simulation model.

ACKNOWLEDGEMENTS

I would like to thank Steffen Richter and Steffen Rackow for their excellent support at the construction of the test rig, especially. Furthermore, I would like to thank the Federal Ministry of Education and Research for its financial support of this research project.

NOMENCLATURE

LAES	Liquid Air Energy Storage
P,el	Electric power

REFERENCES

Großmann, B. et al., 2017. Liquid air energy storage – part of the joint project "Offshore wind solution" at the 14th Cryogenics 2017 (DOI: 10.18462/iir.cryo.2017.0106)

Bohne, N., 2018. Thermodynamische Analyse eines Kältespeichers für einen Flüssigluft-Energiespeicher. Masterthesis, University of Bremen, Germany

Highview Power: https://www.highviewpower.com/technology/; visited 2019-Jan-10