NEWSLETTER

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PUBLIC OVERVIEW OF HESS PROJECT

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Selection of the optimal sealing material for the mine shaft lining serving as a low-pressure CO_2 tank in HESS

Transforming former mining shafts into energy storage facilities is an innovative way to extend the life of industrial infrastructure and support renewable-energy integration. Mine shafts originally built for coal extraction can be adapted for HESS, helping stabilise power systems that rely on variable wind and solar generation. This transformation, however, brings engineering challenges - especially the need to protect the concrete lining. Depending on the technology, the lining must withstand water exposure and cyclic loads (PSH) or remain fully airtight to prevent CO_2 leakage into surrounding rock (CGES). Ensuring long-term durability therefore requires the use of robust protective coatings.

As part of WP4, the project team evaluated available sealing and barrier-coating systems for concrete, focusing on polyurea, polyurethane and epoxy technologies. Based on this assessment, two Sika systems were selected for detailed testing: Sikagard® WallCoat T, a thin-film epoxy providing excellent impermeability on stable substrates, and Sikagard® M 790, a flexible Xolutec® membrane capable of bridging microcracks and accommodating substrate movement. Together, these coatings enable the evaluation of systems across the full range of conditions found in both modern and aging mine shafts. Concretes protected with Sikagard® coatings (M 790, WallCoat T) were subjected to comprehensive assessment using gas permeability, water permeability and corrosion resistance tests.

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Characteristics of Sikagard® coatings

Sikagard® WallCoat T is a thin, two-component epoxy coating (~0.25 mm dry film) that offers excellent impermeability to gases and liquids, low water absorption, and strong carbonation resistance. Its easy application and low material use make it ideal for stable concrete surfaces with minimal deformation, such as technical chambers and low-stress shaft sections.

Sikagard® M 790, a thick-film Xolutec® membrane (0.7-1.1 mm), provides exceptionally low gas permeability, high chemical resistance, and superior crack-bridging performance. Designed to handle ground movement, thermal fluctuations, and pressure cycles, it maintains adhesion and integrity even under dynamic conditions typical of deep shafts. Although more expensive and demanding to apply, its longer service life and reduced maintenance needs often make it the more cost-effective option where substrate movement is expected.

Both Sikagard® coatings are primed with a two-component mineral substrate primer, Sikagard® P 770. This improves adhesion and prevents the formation of pinholes or bubbles on the surface of the cured coating. Sikagard® P 770 has good moisture tolerance and can be applied to substrates with high humidity.

Summary of key properties of selected Sikagard ® protective coatings.

Parametr	**Sikagard® WallCoat T** [1]	**Sikagard® M790** [2]
Coating type	Two-component, water-based epoxy resin	Two-component thermosetting membrane Xolutec®
Vapor permeability	Class I, sD < 5 m	Class II, sD = 41,5 m
Capillary absorbency	w < 0,1 kg/($m^2 \cdot h^{0,5}$)	w = 0,0005 kg/($m^2 \cdot h^{0,5}$)
CO_2 permeability	sD > 50 m	sD = 533 m
Abrasion resistance	94 mg (CS10/1000 g/1000 cycles)	194 mg (CS10/1000 g/1000 cycles)
Adhesion to the ground	≥ 1,0 N/mm² (min 0,7 N/mm²)	~2.9 MPa (dry concrete), ~2.2 MPa (wet concrete)
Bridging cracks	NO	Static: A3 (>0.5 mm), dynamic: B3.1
Aplication	Sensitive to moisture, slow curing	Fast curing, can be applied to damp surfaces
Coating thickness	~ 0,25 mm	0,7 - 1,1 mm
LCC Economics	Beneficial on stable surfaces	Beneficial in objects with a risk of cracking

In summary:

- Sikagard® WallCoat T is a cost-efficient solution for stable, low-deformation environments.
- Sikagard® M 790 is the optimal choice for CGES shafts requiring long-term tightness and crack-bridging capability.

Together, these systems provide a robust toolkit for ensuring airtight, durable concrete linings in compressed-gas energy storage applications.

Gas permeability tests

As part of the project, gas permeability tests were carried out on materials intended for CGES pressure-vessel construction. The objective was to assess how concrete class and Sikagard protective coatings influence the tightness of the structure under operating pressure conditions. Measurements were performed using the steady-state flow method with helium as the reference gas, ensuring high sensitivity and the ability to detect even microscopic transport paths in concrete. This approach provides a reliable basis for evaluating CGES system tightness and selecting suitable materials and coatings. A dedicated test stand was developed for these studies, enabling steady-state permeability measurements on small concrete cylinders, both coated and uncoated. The setup includes precise inlet-pressure control,

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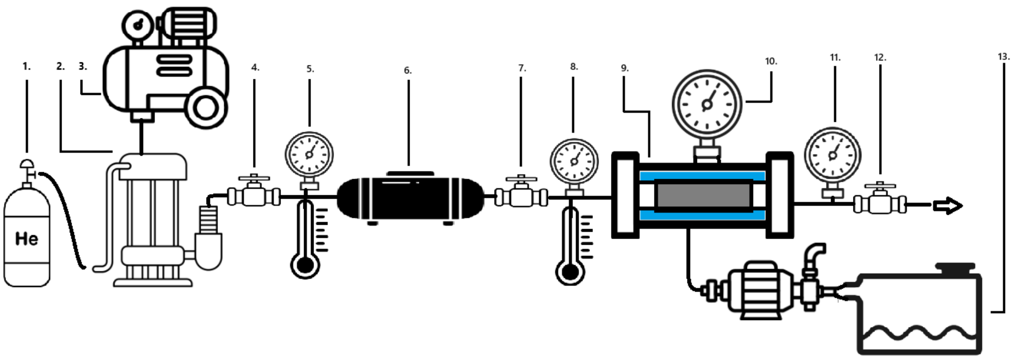
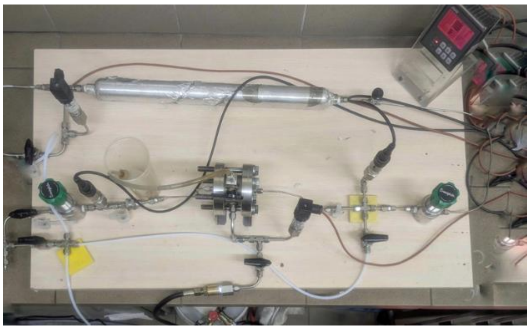
secure specimen sealing, and instrumentation capable of measuring extremely low gas flow rates - all essential for assessing barrier performance in CGES applications.



Lab stand for gas permeability tests; 1. Helium cylinder (99.999% purity), 2. Gas booster, 3. Compressor, 4. Inlet valve, 5. Pressure gauge and thermometer, 6. High-pressure reservoir, 7. Secondary valve for isolating the reservoir from the specimen line, 8. Pressure gauge and thermometer, 9. Specimen holder, 10. Pressure gauge, 11. High-precision manometer, 12. Flowmeter and data acquisition unit, 13. Hydraulic pump with water reservoir.



Parameter	**Value/Specification**
Working gas	He
Operating pressure	60 to 50Bar or 60 to 1atm
Temperature control	Fixed at 20°C ±0,1 °C
Specimen dimensions	Ø25 mm × 30 mm
Concrete classes	C20/25 and C35/45
Coatings tested	Sikagard® WallCoat T, M790
Confining pressure	90 Bar±2

Concrete samples prepared according to EN 206 and EN 12390-2 were tested to evaluate their suitability for CGES applications. The results show that C35/45 concrete offers roughly three times lower gas permeability than C20/25 due to its denser microstructure. However, even C35/45, with an average permeability of 1.37×10^{-4} mD, cannot ensure full gas tightness under long-term compressed-gas storage conditions. Applying Sika protective coatings dramatically improved performance. The M 790 coating reduced permeability by three orders of magnitude (5.54×10^{-7} mD) and the WallCoat T coating by four orders of magnitude (3.62×10^{-8} mD) compared to the reference C20/25 concrete sample (4.75×10^{-4} mD).

These results clearly demonstrate that protective coatings are essential for limiting gas migration in pressure ranges up to 60 bar, making them a critical requirement for adapting mining wells to CGES applications.

Large-scale scenario: pressure losses in a cylindrical reservoir

Laboratory tests on concrete samples - both uncoated and protected with the low-permeability Sikagard® M 790 coating - were used to model gas losses in a vertical tank (8 m diameter, 1000 m height, 1 m wall thickness) filled with helium at 60 bar. The results demonstrated a striking difference in tightness between the two configurations. After just 12 hours of operation, the uncoated concrete showed a pressure drop of 0.086 bar, whereas the Sikagard®-coated concrete recorded only 0.00015 bar. This represents nearly a three-order-of-magnitude reduction in gas permeability and up to a 600-fold decrease in gas loss, highlighting how crucial barrier coatings are for the performance of compressed gas energy storage systems.

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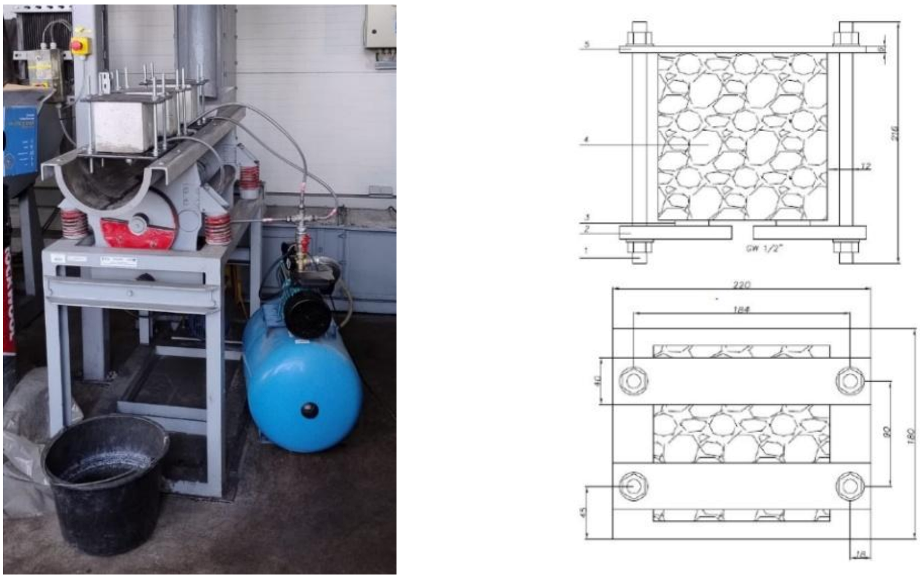
Enhanced tightness directly improves the economic and operational efficiency of CGES installations: it prolongs effective storage time, reduces the need for gas replenishment, lowers compressor load, stabilizes system behavior during daily cycling, and decreases operating costs.

Yearly gas-mole losses for helium at 60 bar were as low as 0.18%, already an excellent result. Importantly, helium - due to its very small atomic size and high diffusivity - represents a worst-case scenario. Actual CGES systems will operate with CO_2 at much lower pressures, making real permeation rates negligible. Thus, the expected mass loss of CO_2 under operational conditions can be considered insignificant.

Water permeability tests

As part of the HESS project, water and brine permeability tests were carried out under pressure (6 bar) on structural concretes C20/25 and C35/45, both uncoated and protected with Sikagard® WallCoat T and M 790 coatings, in accordance with PN-EN 12390-8.



a) b)

Test stand for testing liquid permeability through concrete (a), test stand diagram (b), 1. Bolt, 2. Steel plate, 3.Flat gasket, 4. Concrete sample, 5. Pressure flat bar, GW1/2" - pressurized water connection.

a) b)

Samples of concrete class C35/45 (a) and concrete coated with Sikagard® M790 (b) after completion of permeability tests using brine.

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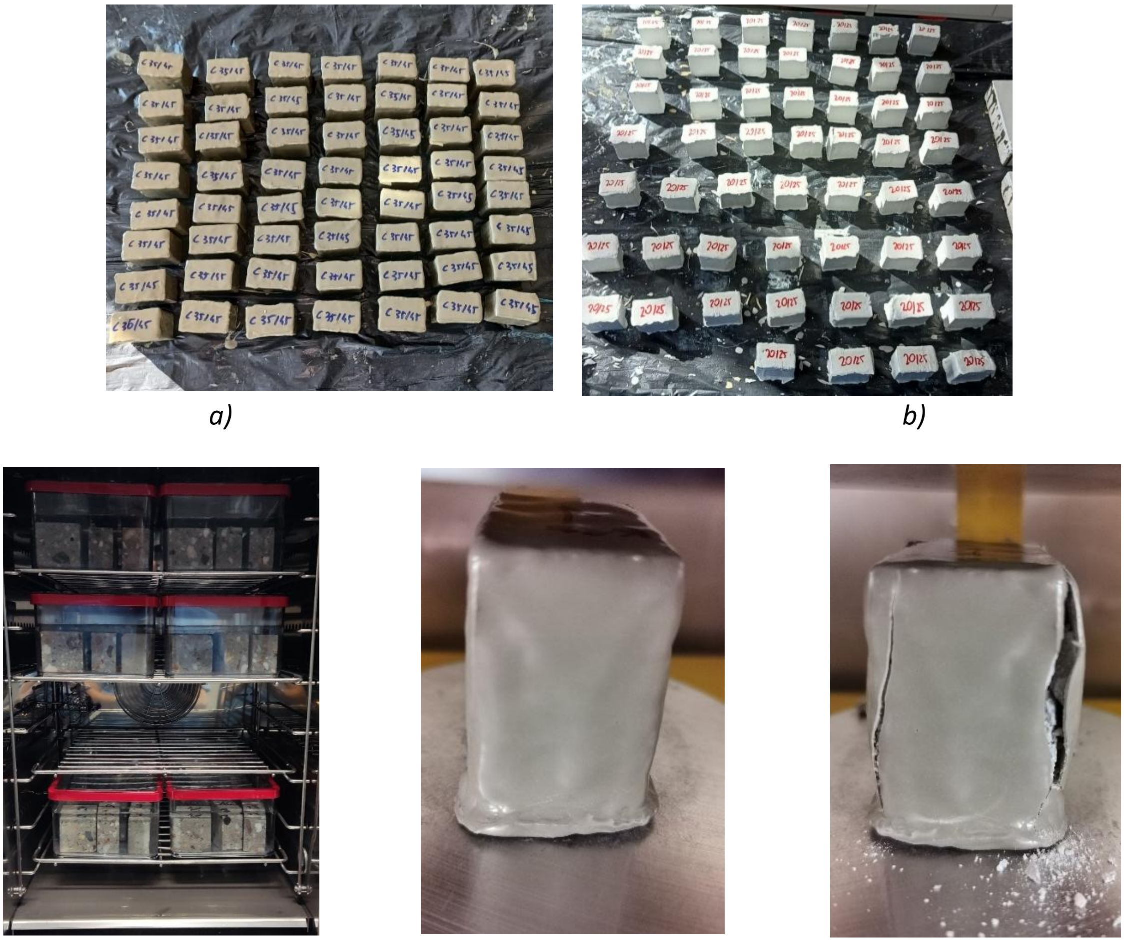
The results showed clear differences between the concrete grades: C35/45 exhibited stable and low penetration depths for both media, confirming its dense and homogeneous microstructure, while C20/25 showed higher variability and greater sensitivity to the type of liquid. Concrete samples coated with Sikagard® M 790 and Sikagard® WallCoat T demonstrated complete resistance to liquid penetration, both after 72 hours and after two months of testing. The coatings also improved the mechanical performance of the samples, increasing their fracture resistance. Both systems performed comparably within the test duration. Overall, the results confirm that properly coated concrete is a suitable construction material for PSH tanks, providing very low liquid permeability and high durability under operational conditions.

Corrosion tests

Because the PSH tank's structural material is exposed to prolonged contact with water and brine, the HESS project conducted long-term corrosion resistance tests on C20/25 and C35/45 concretes - both uncoated and coated with Sikagard® WallCoat T and Sikagard® M 790. Samples were immersed in 5% solutions of chlorides, magnesium, sulphates, and hydrochloric acid, as well as in a brine solution reflecting real mine environments. Exposure periods of 28, 90, and 180 days were used. After each period, the samples were assessed for mass loss, dimensional changes, surface condition, and compressive strength. These tests provided a comprehensive assessment of the durability of coated and uncoated concrete under the aggressive chemical conditions relevant to PSH applications.



Concretes covered with coating Sikagard® M 790 (a), Sikagard® WallCoat T (b), corrosion immersion chamber test (c), compressive strength test for coated samples before compression test (d), after compressive destruction (e).

For concretes coated with both Sikagard® coatings, no sample mass loss was observed during the test period of up to 180 days of exposure to corrosive factors. The compressive strength of the tested concretes treated with both coatings was within the strength classes of both types of concrete. Thanks to the coatings, the underlying concrete remained largely unaffected, preserving its compact and stable structure. Most of the coated samples showed smooth, uniform surfaces with no signs of flaking. Only the Sikagard® WallCoat T coating exhibited noticeable changes when exposed to a 5% acid solution, where surface blistering was observed - indicating reduced resistance under strongly acidic conditions. In case of the Sikagard® M 790, no changes in the coating structure were observed excluding a colour change (from grey to rotten green) upon exposure to acid. Changes were observed on both types of coatings after 28 days of exposure.

a)

b)

c)

d)

Sikagard® WallCoat T sample before test (a), sample after 180 days of exposure in acid solution (b), Sikagard® M 790 sample before test (c), sample after 180 days of exposure to acid solution (d).

Corrosion tests were also carried out under 6-bar CO_2 pressure - conditions representative of a CGES storage tank. The samples were exposed to water, 5% chloride, magnesium, and sulphate solutions, as well as brine, reflecting real mine environments. Testing lasted up to 60 days, allowing assessment of coating performance under combined chemical and CO_2-rich conditions.

System for testing corrosion resistance under 6-bar CO_2 pressure.

In CO_2-saturated corrosion tests, both coatings remained stable with no signs of degradation. Sikagard® WallCoat T showed only minor surface changes related to the mildly acidic conditions created during CO_2 dissolution, but these did not affect the concrete's mechanical strength. Overall, both Sikagard® WallCoat T and Sikagard® M 790 provided effective protection in chloride-, sulphate- and magnesium-rich environments, high-salinity mine waters, even acidic conditions, and under CO_2 pressure, with M 790 showing the highest resistance. Coated samples outperformed uncoated concrete, particularly in highly aggressive environments.

Tests conducted as part of the HESS project confirmed that protective coatings or concrete are essential to limit gas migration in the CGES system. Both Sikagard® WallCoat T and Sikagard® M 790 - applied over Sikagard® P 770 - ensure zero liquid penetration, significantly reduce gas permeability, and provide effective anti-corrosion protection in aggressive environments. WallCoat T proved to be a cost-effective and efficient solution for stable concrete surfaces, while M 790 offers excellent, long-term sealing and crack-bridging properties in areas exposed to mechanical or environmental stress. Overall, both systems form a complementary and reliable sealing strategy, providing durable, airtight mine shaft linings suitable for compressed CO_2 energy storage in HESS systems.

The work resulted in deliverable ***D.4.3. Lining materials selection and properties***

References:

[1] https://pol.sika.com/pl/budownictwo/zabezpieczenie-betonu/zabezpieczenia-powokowe/sikagard-wallcoatt.html
[2] https://pol.sika.com/pl/budownictwo/hydroizolacje/ochrona-wod-gruntowychioczyszczalnieciekow/pow-oki/sikagard-m-790.html

We invite you to explore more details of the work on the HESS project website
https://itpe.pl/en/hess/

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