Mutual benefits of combining potash production and abandonment of underground storage facilities

Paper track: Salt and the Environment

Keywords: cavern abandonment, potassium production, brine discharge, flooding, environment

Abstract

The technical paper describes the combination of operational processes of two German companies for the benefit of both sides.

On the one hand there is a gas storage facility in Central Germany showing geomechanical wear after 40 years of cyclic gas storage operation. The long term abandonment of some caverns is prepared.

On the other hand there is one of the world leading producers of potassium and other salt products, that has to cope with saline solutions as a byproduct without a market. Disposal options like discharging into a river and injecting into an aquifer are limited and shall be reduced to a minimum.

The idea of a win-win-project was established: The re-utilization of large quantities of process brine was offered in order to replace the gas and flood the cavern. For this purpose, the fluid has to be transported via train and truck over several hundred kilometers, which implies some logistic challenges.

The brine handling facility was planned and built on an existing site. The objective was to implement infrastructural adjustments to transfer the discontinuous unloading of tankers and containers to a continuous brine delivery process into the cavern. The resulting discharge capacity of up to 100 m³/h allows the flooding of one cavern within approximately half a year.

In the present case magnesium chloride brine is used for flooding. This brine is much more corrosive than sodium chloride brine or fresh water. Therefore, the effects and requirements on surface and subsurface equipment had to be investigated in advance of the intended flooding process.

Strong material requirements and environmental protection regulations had to be met for newly constructed parts as well as for the integrated inventory. All parts that are exposed to the brine, such as tanks, pumps and pipelines, had to be designed accordingly: double-walled or lined, fail safe and semi-automatic.

The dissolution inside the cavern will be reduced to a minimum and re-crystallization is negligible. The sustainability of the technical and geological barriers against the pressures after the plug and abandonment of the well was theoretically proven, even under the assumption of worst case conditions. In 2016, the facility and the procedures were approved by the mining authority and environmental agencies and subsequently the successful operation was commenced.

1 Development and Geology of the Project Location

The project site is located in Central Germany, within the federal state of Sachsen-Anhalt. Industrial activities to exploit the salt deposit commenced in the mid 1880ies by construction of first mine shafts. The Potash production started in 1890 and most recently when the shafts for the rock salt mine were constructed in 1912 the location was established as one main location for industrial salt (both Rock salt and Potash) production in Central Europe. Today the mining area of the minefield encompasses more than 40 km² (15.4 sqmi).

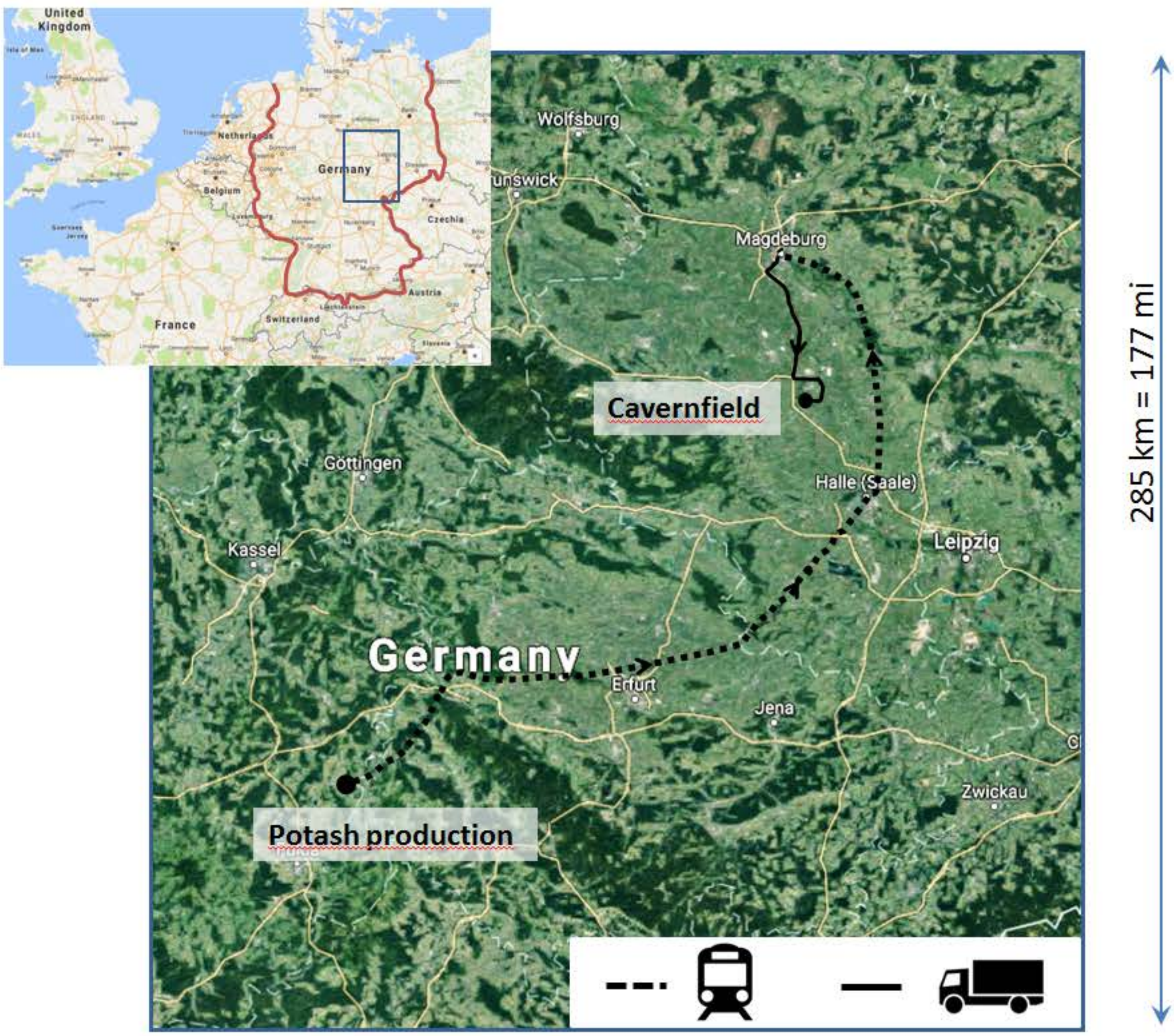

Figure 1: Locations of the two sites and transport routes for the brine

The salt cavern construction for brine production in the area started in the mid 1960ies. The first cavern for LPG storage was commissioned in 1969 and further cavern wells were drilled. The natural gas storage facility has been operating for more than 40 years up to now and was developed in several extension steps to meet the requirements of growing domestic consumption of natural gas and increasing safety of supply.

The following very brief geological description is focused on the cavern field only. The west-east striking Zechstein salt pillow is an important Stassfurt salt accumulation in the southeastern part of the North German basin. It has an oval shape with an extension of about 100 km² (38.8 sqmi). The surface of the Zechstein rock salt is at the crest in a depth of about 200 m (600 ft) gently dipping to the rim synclines to depth of 550 m (1650 ft). Here the Zechstein series is subdivided into 4 major cycles (Werra Z1, Staßfurt Z2, Leine Z3, Aller Z4). The structure forming Stassfurt-Steinsalz (Rock salt) shows NaCl contents of more than 95% and is characterized by remarkable variations in thickness, resulting from salt tectonics. It forms the host rock of the caverns with a thickness of up to 650 m (1950 ft) in the centre of the salt pillow.

2 Storage of Hydrocarbons in Salt Caverns

With the further development of gas industries and the related increasing of gas consumption provisioning of natural gas became more and more important. The first recorded underground gas storage site opened in 1915, in Welland County, Ontario, Canada. In 1916, the Zoar field, near Buffalo, New York, became the first storage project in the USA and continues to operate today. The use of solution mined salt caverns for the storage of both liquids and gases is believed to have been first conceived in Canada in the early 1940’s and the storage of liquid hydrocarbons in salt caverns first occurred in Keystone, Texas, USA in 1950 and spread rapidly in the early 1950’s in North America and several European countries.

The use of salt cavern storages has been expanded considerably during the last decades to include the permanent storage or disposal of numerous wastes and the storage of various industrial gases, LNG and other liquids. Permanent waste disposal via salt caverns include the by-products of industrial plants, the petroleum and mining industries. Furthermore options for storing carbon dioxide, and nuclear waste are serious R/D items.

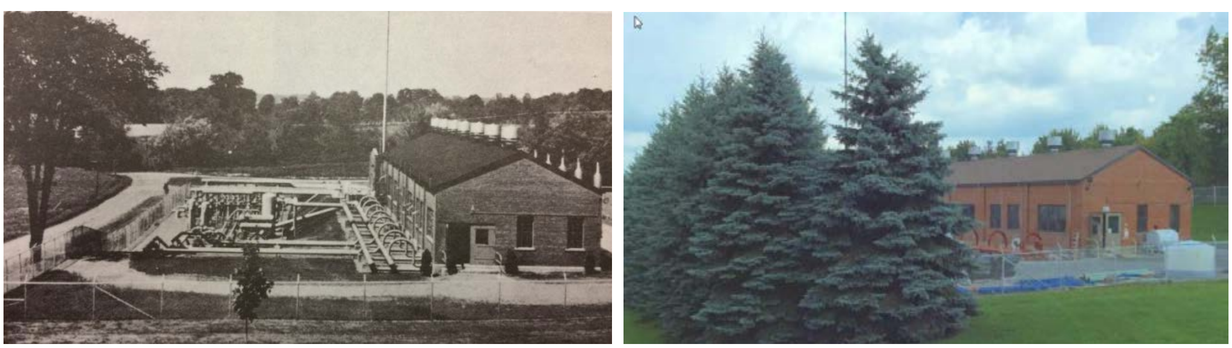

Figure 2: Operational storage site in Keystone/Texas (historic photo and current situation)

The Petroleum industries of Texas and Alberta extensively use salt caverns to dispose of non-hazardous by-products from petroleum drilling and production operations. The depth, stability, size and excellent containment properties of underground salt caverns make this form of storage increasingly attractive for a number of temporary and permanent storage applications worldwide.

Salt production by solution mining and the re-use of the leftover hollow space into the salt for storage issues is a nearly perfect business synergy and a win-win situation for involved companies. In the project area a salt producer uses the salt for his own purpose. For a possible future usage of salt production caverns as natural gas storage caverns there is a special leaching performance program to develop the cavern in a defined shape and volume.

A typical cavern in the project area shall be designed on several parameters so that it can be used for later gas operations.

The last cemented casing shoe has to be below 500 m to allow a maximum gas pressure of 100 bar (g) (1,450 psi). Due to the differing height of the deposit caverns at the location have a variety in volume of 200,000 to 600,000 m³. The older ones which are to be flooded are on the lower end of that range. A cavern of for example 250,000 m³ produced about 2 Mio m³ of brine or 0.5 Mio t of salt. After the production phase a working gas volume of about 22 Mio m³N has been used for over 30 years and at the end of this life cycle the geometrical volume is filled with production solutions.

3 Brine Discharge

Potassium and other salt products are produced on several locations in Germany and all over the world. Different methods of separating the potassium are used. Parts of the leftovers are saline solutions of varying density and mineral load. Disposal options like discharging into a river and injecting into an aquifer are limited and shall be reduced to a minimum for economic reasons. In the current case the potash producer had to reduce the production output of some plants because of shortages in the disposal of the brines.

3.1 Solution Processes

As explained above several brine compositions need to be discharged. Three types are given in table 1.

g/l	low MgCl2	medium MgCl2	high MgCl2
KCl	40	100	60
MgCl2	62	120	270
MgSO4	90	75	50
NaCl	180	115	40
density	1,26	1,26 – 1,3	1,3

Table 1: Typical load and density of delivered brine

There will be interactions between the already pumped in water (now saturated to pure NaCl brine), the delivered $MgCl_2$-brine, brine of varying composition and the salt rock. The saturation points of the solutions shift permanently when they come into contact with dissolved or undissolved components. Thus crystallizes e.g. Halite, Sylvinite or Glauber´s salt in significant magnitudes – both on surface and subsurface. Inside the cavern crystals will residues in the sump. Problems - e.g. the plugging of the flood stream - have not yet occurred. Interactions between the brine and the rock itself are not to be expected to a significant extend, due to the purity of the halite deposit and the fact that the brine is saturated with sodium.

Brine is delivered with temperatures between 10 and 30°C, while undisturbed rock temperature is expected at a magnitude of 23°C. Therefore temperature equalization as well as the interactions between solvent components and the rock salt come to a halt only after several years. During the monitoring phase after flooding the real equalization time will be observed.

3.2 Existing Subsurface Installation

The existing subsurface installation is shown in Figure 3.

The connectors of the 11 ¾” last cemented casing as well as the 8 5/8” production casing are welded. Therefore both are considered – and of course tested – as gastight first and second barrier. The double walled liner substitutes a production packer in that installation and is also welded and tested for gas tightness.

The 5“ flooding string reaches down to the sump. Therefore flooding fluid is injected at the deepest point inside the cavern and a permanent mixture of fluids is expected.

The suitability of the existing subsurface installation has been checked by a new well integrity analysis, due to the higher corrosion rate of $MgCl_2$-brine compared to the one of NaCl-brine. Especially corrosion wear at the 8 5/8” production casing and - as a worst case scenario – at the 11 ¾” were calculated. The safety margins for burst, collapse and axial strength are well abided, over the monitoring phase before the final closure of the well. No special requirements for the subsequent closure of the borehole are known.

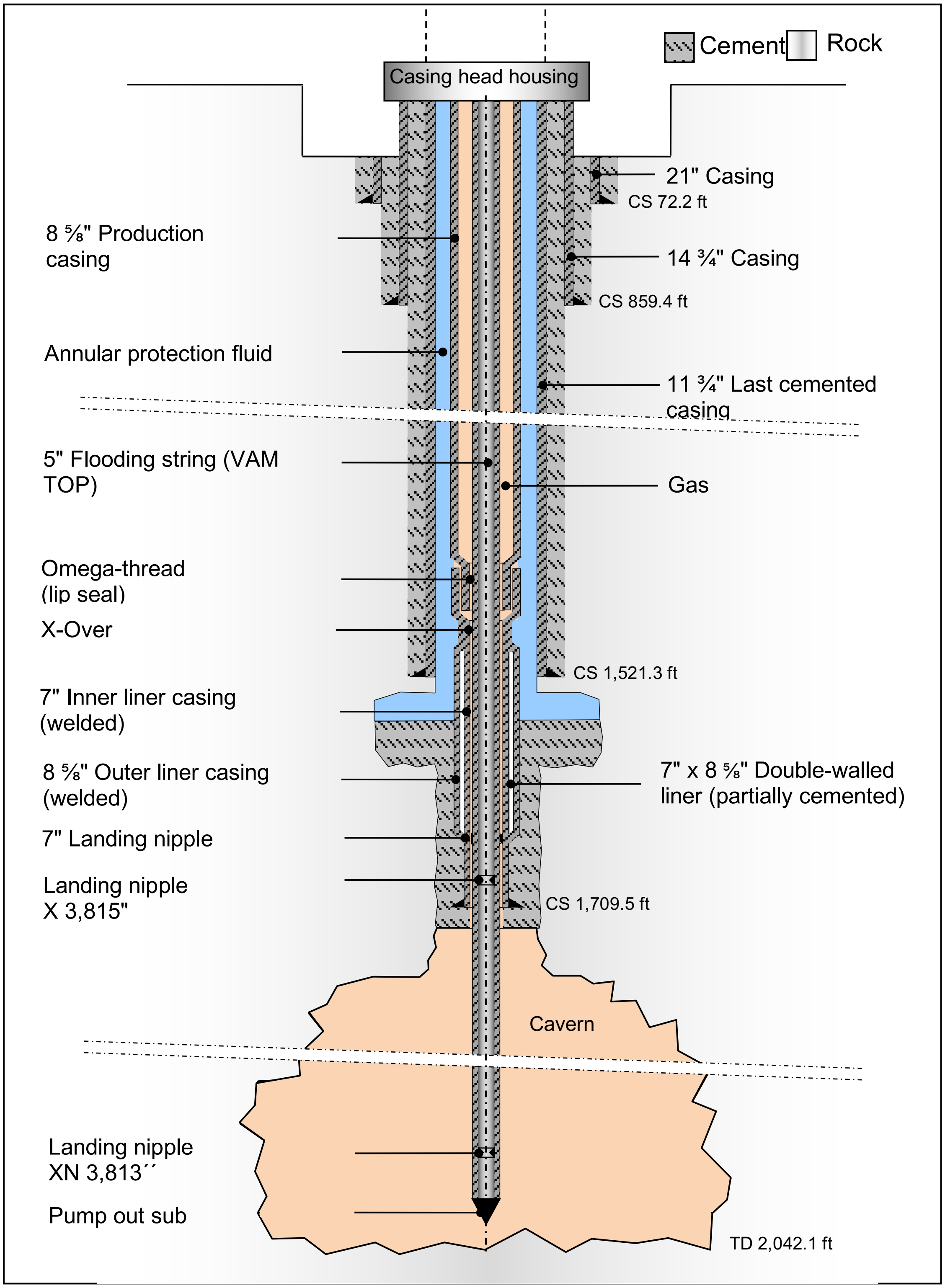

Figure 3: Subsurface cavern installation

3.3 Long Term Stability – Rock Mechanics

The usage of the MgCl brine as flood medium instead of water has also been assessed by the Institut für Geomechanik (IfG, Leipzig, Institute for rock mechanics). Negative impacts could not be found. By contrast with the usage of water it was stated:

- after-effects due to solution processes are reduced to a negligible level
- as a result, contour changes during the flooding can even be reduced
- the higher density of the MgCl brine results in a higher internal pressure and thus counteracts the convergence in the long term.
- as the brines from potash production are warmer the time until temperature equalization in the cavern is shorter.

4 Surface Aspects

Related to existing disposal bottlenecks on part of the potash production, the demanding task was to develop and construct a well-designed and reliably working plant concept for the transport and disposal of highly corrosive brine within a limited time frame.

Due to the existing infrastructure of at the project location the size of land and buildings, the available access routes and connecting conditions were fixed as boundary conditions.

Engineering, design and construction of industrial plants are subject to strict approval procedures in Europe and Germany, which can be very time consuming. The project team therefore had to act under the legal provisions of German Mining Law with its strict given construction and environmental requirements.

The schedule of such projects is usually structured in basic and detail engineering as first steps, which have to be submitted to notified authorities for approval and have to be documented as well as confirmed in detail. A corresponding construction permission may only be issued after all requirements have been approved and fulfilled in accordance with the applicable legal order.

The next step in project workflow is to start tendering and procurement measures under market conditions.

Both steps are time consuming. Furthermore as Northern Europe is subject to changing seasons there is a period of 3 months a year (wintertime) where building and construction activities can be aggravated or interrupted.

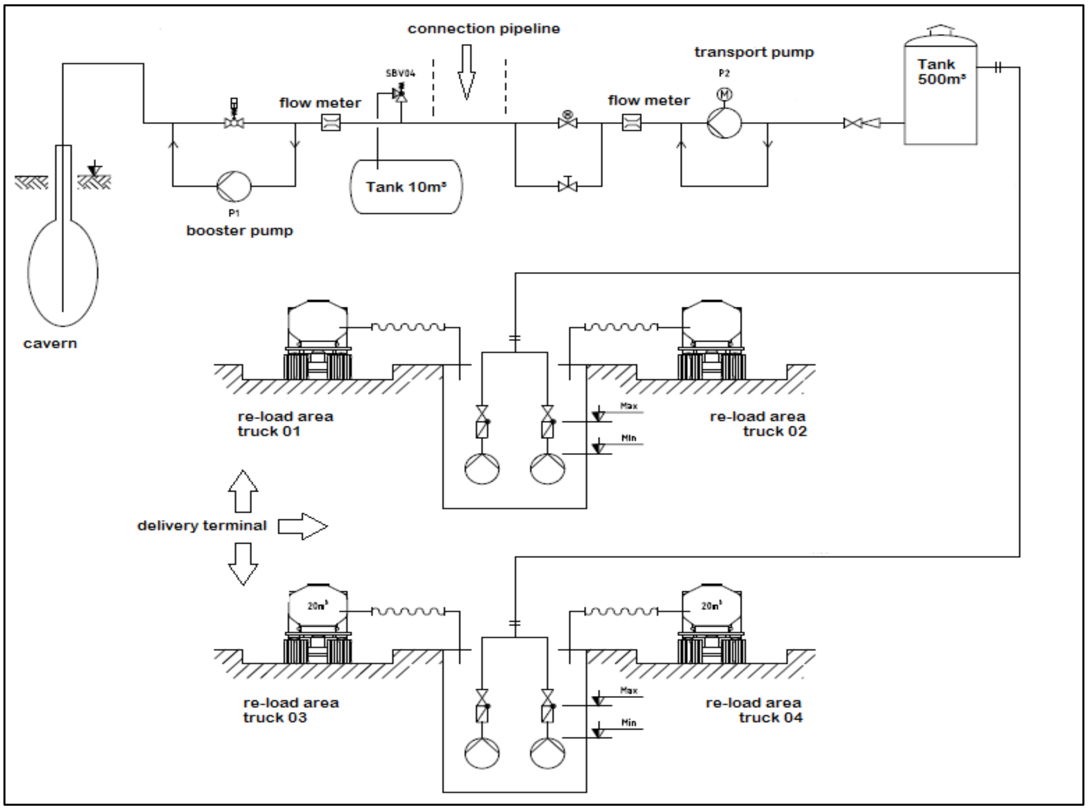

Figure 5: Technical scheme (principal) of surface equipment

The contract awarding for engineering works, approval procedure and construction on site took place in the second half of the year with the aim of completion and commissioning at the end of the year 2016.

The main planning and procurement measures had to be processed in parallel before the official building permit was granted. Based on a large mutual trust there was a high degree of well balanced risk-taking on parts of both contracting parties, to reach the project aims.

Based on results of conceptual study the design of a re-load terminal to discharge the truck-supplied brine was needed only driven by gravity and container pressure in the order of magnitude of 20 m³ per truck or 2400 m³ (approx. 16 bbl or up to 90 Trucks) per day at the site.

A flat-bottom tank at the site which was out of operation was re-used for intermediate storage. Prior to this re-use it had to undergo also some planning and revamping procedures related to corrosion protection and construction statics before an operation permit was granted.

The planned, approved and constructed delivery terminal consists of 2 underfloor intake structures using double pumps and in total 4 sealed heavy load areas including all necessary access roads.

The main requirement for the underfloor intake structures and the pumps was to guarantee a reliable and safe operation for long term. This was achieved by using appropriate dimensions of equipment and pipes, redundancies were needed and a consequent use of non-corroding materials.

The main purpose of the delivery terminal is the transfer of the delivered brine to the intermediate storage and buffering the continuous flow process of brine into the chosen cavern. The brine is supplied in a starting-up process by an accordingly pressure-delivering process pump and a field pipe system to the cavern well pad. The cavern-filling itself is just only effected by gravity.

Figure 5: Project area with delivery terminal and tank farm

5 Summary

The experiences of the project proved that thinking out of the box could lead to viable solutions for new challenges. For achieving ambiguous targets in schedule and budget it is paramount to establish an effective workflow between planning and construction activities as well as an ahead thinking communication with the authorities involved.

Technically the execution benefited from the existing infrastructure at the project site and the approach of the engineers to use simple installations for easy use and non-corroding materials for the main equipment. Thus a safe and stable operation for the long term could be secured and both project parties take advantage from that cooperation. Furthermore an environmentally friendly technical solution was created for salt and potash producers to enhance the acceptance of their business model in a positive manner.

Similar to a sustainable production of salt in the cavern development for storage issues, this project shows opportunities even after the termination of a period of usage. This artificially cavities can be permanently filled with rest materials of the potash production. A fully production cycle starts and ends by innovative power of salt and potash producers.