Obstruction in a salt cavern: Solution is dissolution

Matthieu Keime, Storengy Deutschland, Berlin, Germany
Yvan Charnavel, Storengy, Bois-Colombes, France
Günter Lampe, Storengy Deutschland, Berlin, Germany
Helge Theylich, UGS[1], Mittenwalde, Germany

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1 Background

1.1 Storengy

Storengy, a company of GDF Suez, spearheads the Group's natural gas storage activities. It currently operates and develops storage facilities across France, the United Kingdom and Germany which sum up to 23 sites and close to 12.5 billion m3 (443 Bcf) in working gas capacity. Storengy is a European leader in underground natural-gas storage and ranks first in marketing storage capacities.

With over 1000 employees, Storengy is in charge of all new storage-related pursuits, planning, development, installation and operating activities, as well as the commercialization of services directly or indirectly pertaining to natural gas storage. Storengy's objective is to strengthen its position among the five worldwide leaders in underground gas storage.

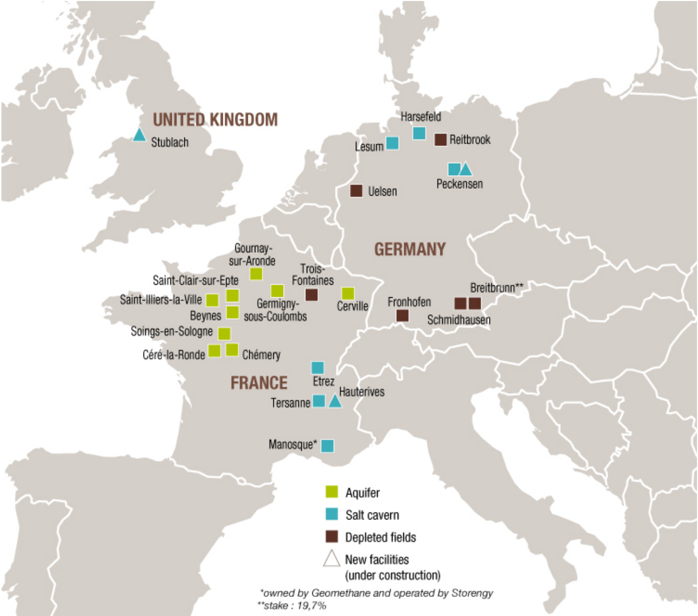

Fig. 1: Storengy's storage sites

In Germany – the biggest European gas market – Storengy is the 4th largest storage provider with 7 storages in operation (both depleted fields and salt caverns) and a 19.7% stake in the Breitbrunn-Eggstädt storage.

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[1] Untergrundspeicher- und Geotechnologie-Systeme GmbH

1.2 Peckensen Gas Storage

The Peckensen gas storage located about 100 km east of Hanover has been in operation since 2002. A working gas volume of approximately 220 mcm (7.8 Bcf) can be stored in the three salt caverns currently operated. Storengy is expanding its storage capacities at the Peckensen site by leaching two more caverns which will increase the storage capacities up to approximately 400 mcm (14.1 Bcf) by 2014.

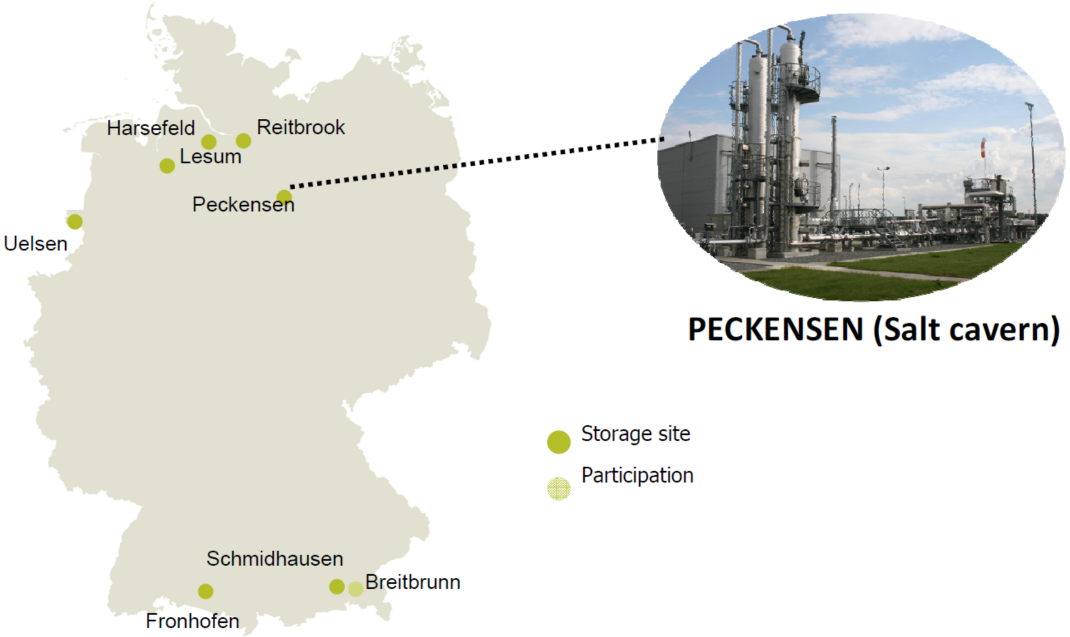


Fig. 2: Storengy's storage sites in Germany

1.3 Salt caverns for underground gas storage

The caverns are created in a salt dome 15 km long, 2.5 to 4 km large, and 2 km thick, lying 700 m below ground. The salt is almost pure halite with less than 5 % insoluble content. This salt dome is large enough to host up to 50 caverns.

Each cavern is designed for an “egg” shape. With 200 m height and 100 m maximum diameter for a usable geometrical volume between 500 000 m³ and 750 000 m³, each cavern would be large enough to host both Berlin's Brandenburger gate and Paris' Arc de Triomphe.

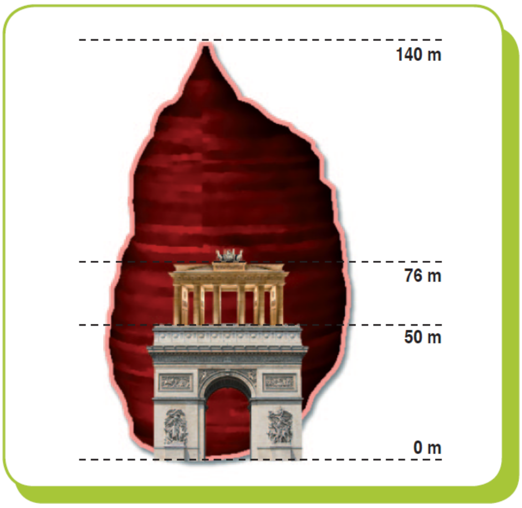


Fig. 3: Typical salt cavern for natural gas storage

A petroleum type well links the surface to the 1300 m deep cavern. The caverns are created by solution mining:

- Two concentric pipes in the well
- Injecting water through annulus in the case of reverse leaching *(or central pipe in the case of direct leaching)*
- Water dissolves salt thus enlarging the cavern
- Brine (water+salt) returns to the surface through central pipe in the case of reverse leaching *(or annulus pipe in the case of direct leaching)*
- Blanket material (nitrogen for Peckensen) is injected in the outer annulus and floats on brine so as to prevent salt dissolution of the cavern roof.
- Insoluble materials drop to the cavern bottom.

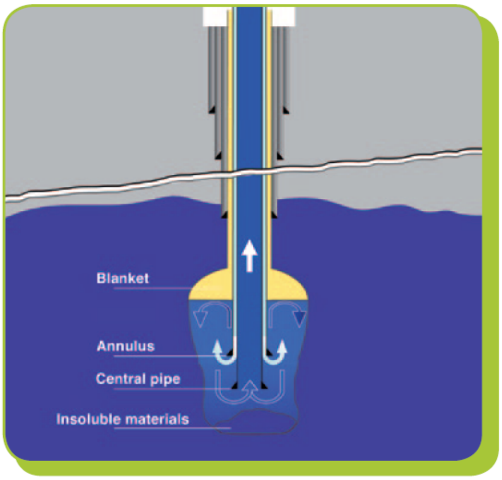


Fig. 4: Solution mining

By changing blanket depth, pipes depths, and water injecting pipe, one can create the desired cavern shape.

Creating such a cavern usually lasts 3 to 4 years, requires 4 to 6 million m^3 fresh water and leads to the dissolution of 1 to 1.5 million tons salt.

Once the cavern has reached its final shape, and the well is fitted with equipment for gas operation, natural gas is injected under pressure into the cavern through the annulus and brine pushed to surface by the central pipe until the cavern is full of gas.

Natural gas is stored in its gaseous form; gas pressure in the cavern changes when gas is injected or withdrawn. The usable gas volume between minimum (70 bar) and maximum (220-230 bar) pressure is around 60-90 million m^3_N for each cavern. With the gas quantity stored in one cavern, 30,000 to 45,000 households could be supplied over a year.

1.4 Specific problematic of well Ellenberg 2: Finding carnallite while drilling

Even though more than 30 wells had previously been drilled through this domal salt structure for exploration and production purposes in the Altmark gas field (which is partly located below the Peckensen salt dome), and cavern Ellenberg 1 had been developed, Ellenberg 2 (ERG2) drilled in 2005 was the first well where carnallite salt was found at the storage cavern depth. Since then, four other wells were drilled in the vicinity, one of them with the cavern developed and now in gas operation, two of them currently under leaching, the last one as a spare well. None of them showed any indication of carnallite. Carnallite, a magnesium / potassium salt ($KMgCl3 \cdot 6(H2O)$), dissolves several times faster than halite, so creating a cavern in halite with carnallite seam(s) is disadvantageous to its shape and volume.

In ERG2, carnallite was found at mid cavern depth with approximately 2 m (6 ft) thickness, with no carnallite trace anywhere else in the well. At Storengy, together with the engineering company in charge of the leaching, Untergrundspeicher- und Geotechnologie-Systeme GmbH (UGS), the decision was taken, to develop the cavern nonetheless. The solution mining design had to be changed in order to minimize the carnallite impact and preserve the cavern shape and the volume for gas storage as far as possible.

1.5 Geological conditions called for new design for cavern Ellenberg 2

The dissolution rate of carnallite is several times faster than that of halite. This results in cavern growing much faster into the direction of carnallite which is unfavorable for the cavern shape and thus for the cavern volume as the cavern had to stay within the limits of the geo-mechanical study (max radius/diameter and shape).

At this stage, carnallite was only known from “crossing” the well at mid cavern height with 2 m (6 ft) thickness, but neither its dipping (assuming it is plane) nor its extension were known. In order to limit the impact of carnallite, it was decided to develop the cavern in 3 steps:

- Step 1 : develop a lower cavern part below the carnallite,
- Step 2 : develop a 8 to 10 m diameter (26-33 ft) link at carnallite depth,
- Step 3 : develop an upper cavern part.

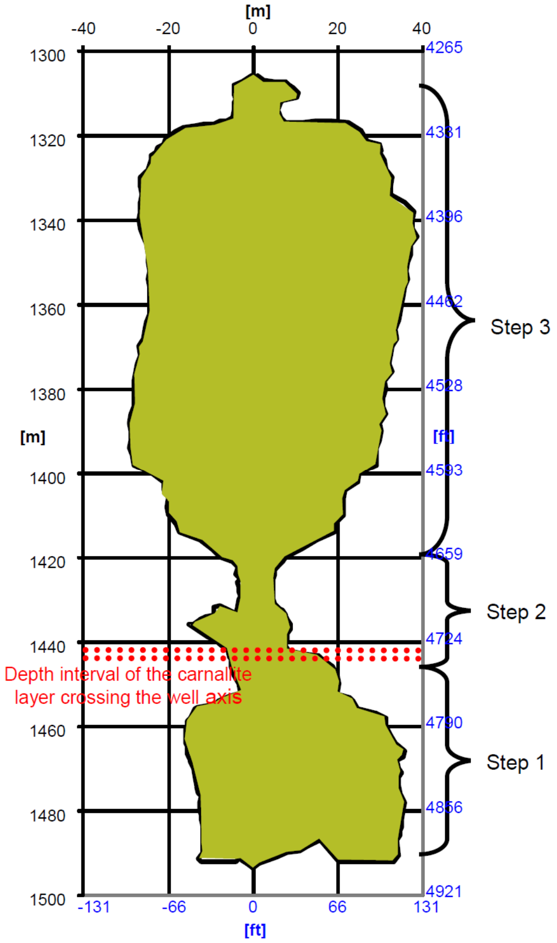


Fig. 5: Cavern Ellenberg 2 - Leaching design

To achieve the planned design and optimize the leaching process both direct and reverse leaching had to be used. The manifold installed on the cavern site and which allowed easy and rapid circulation changes was an advantage in this context. Extensive brine analysis on samples was conducted at least once a week, with special attention to magnesium and potassium ions, thus allowing the monitoring of carnallite dissolution and consequently constant adjustment of the leaching program.

During Step 1 the development of the lower cavern part had to be reduced because of carnallite presence in this area. By the time the cavern radius increased to 20 m (66 ft), leaching in the carnallite direction reached the maximum distance of 60 m (197 ft) and solution mining had to be stopped.

During Step 2 carnallite higher dissolution rate was expected. The cavern was developed in the carnallite area until a diameter of 8-10 m (26-33 ft). This was a compromise between sufficiently widening the middle cavern part to ensure long term access to the cavern lower part and limiting the carnallite dissolution in this area. This area had to be large enough to access the lower cavern part later on and also for the insoluble materials (coming later from upper cavern development) not to plug the link. On the other side it had to be small enough to limit the development of the carnallite "layer". In addition, the brine saturation in the area was kept low in order to reduce the leaching time and, even more important, to reduce the differential leaching speed between carnallite and halite. The analysis proved to be correct since the development went within expectations.

Step 3 was crucial because it was the last chance to create more volume for storage, especially as a lower volume than planned had been achieved during Step 1. All possible measures were taken to stay away from carnallite. The upper cavern part developed almost axi-symmetrically except for the very last stage where carnallite was found again on the cavern side. Consequences on the upper cavern part were minimal as the volume has already been created.

1.6 Occurrence of an obstruction blocking access to lower cavern part

Nevertheless the faster dissolution of carnallite isolated a large block in the cavern lateral wall that ultimately fell down and blocked access to the lower cavern part. Under this configuration, it was impossible to run the debrining string (used to withdraw the brine out of the cavern) into the lower cavern part and thus to fill this cavern part with gas.

The lower cavern part accounted for 1/4 of the total cavern volume, so restoring access to the bottom cavern part was crucial. Without this access the lower cavern part would have been unusable for gas storage over the whole lifetime of the cavern.

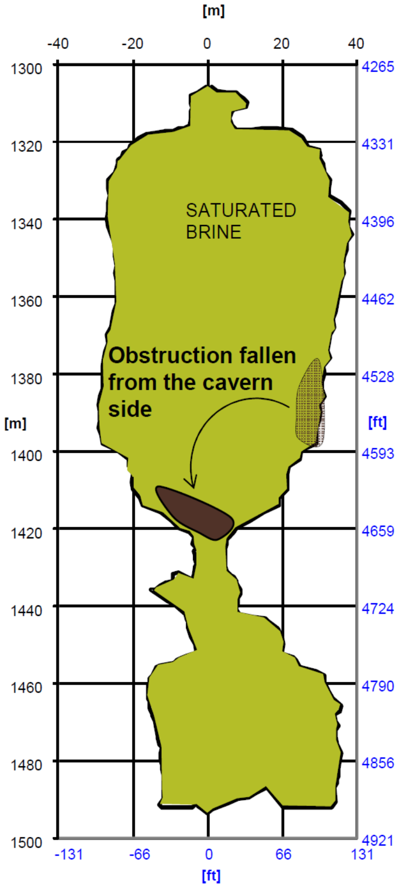


Fig. 6: Obstruction blocking access to lower cavern

2 Methods uses to restore access to cavern lower part

2.1 Solution is dissolution

At first the problem faced needed to be clearly seized. A first sonar survey from above showed that the size of the obstruction was approximately 15 m (45 ft) by 10 m (30 ft). To get access to the bottom of the obstruction – thus allowing to estimate its thickness – it was decided to attempt to drill through the rock mass.

To prevent the drill bit from slipping on the inclined surface of the obstruction and prevent buckling of the drilling assembly, the outer 10 ¾" leaching tubing was used as a guide and the drilling assembly equipped with a downhole motor. After carefully drilling a pilot hole with a milling tool, it was possible to drill with a roller cone bit through the obstruction.

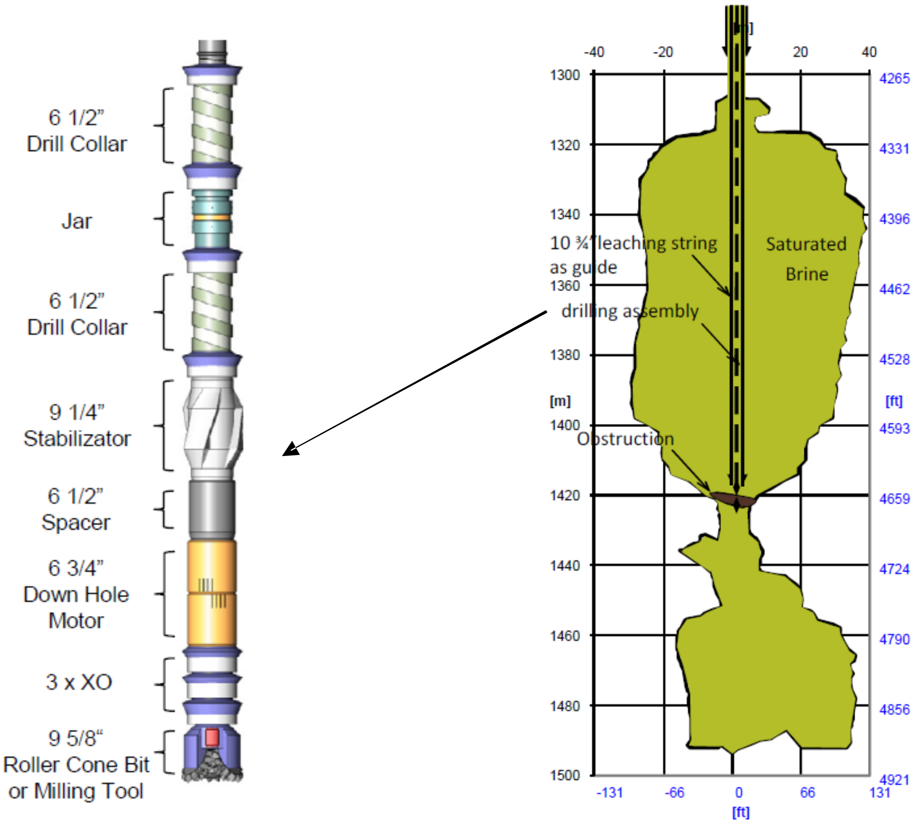


Fig. 7: Drilling through the obstruction

Using these unconventional techniques the obstruction was successfully drilled and the freshly drilled hole could be found regularly by free hanging tools. This way it was possible to get further information on the obstruction geometry as well as to improve the initial situation for further operations.

A second sonar survey from below the obstruction was finally possible and gave the first indication on the thickness of the obstruction: 2 to 5 m (6 to 15 ft). With such dimensions, the obstruction appeared too massive to be mechanically eliminated. The good news was that water circulation during drilling had increased the size of the hole, thus proving that the obstruction was soluble.

A quite obvious solution to restore a "normal" access to the lower cavern part was to lower the water injection tubing through the hole to a depth below the obstruction and resume solution mining. Both the obstruction and the link (between upper and lower caverns) would be leached until the obstruction had shrunk enough to go through the enlarged linking part.

Although this sounds simple and efficient, the anticipated consequences had to be looked at, since solution mining would also affect the entire upper cavern part. This solution would:

- take time (enlargement of the entire upper cavern part),
- enlarge a cavern which had already reached its final shape,
- enlarge (several times faster) the carnallite seam,
- increase the risks of further rock fall.

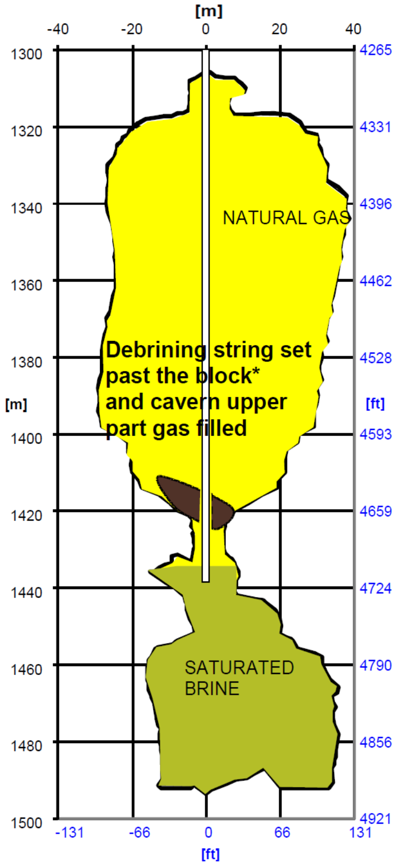
This solution was not implemented as consequences were considered unacceptable.

In order to protect the upper cavern part, and speed up the leaching process, solution mining had to be focused on the problem area. This could "easily" have been achieved by lowering the nitrogen blanket to a level just above the obstruction. "Easily" means filling the whole upper cavern with blanket. This would have been both time consuming (huge quantity of nitrogen to be injected) and non-economical (nitrogen cost).

2.2 Natural gas blanket: Solution Mining Under Gas (SMUG)

The chosen solution was to use natural gas as blanket. This way, first gas filling of ¾ of the cavern (i.e. the upper cavern part) would be carried out first, thus no additional time was needed for lowering the blanket level, and no additional cost for the extra blanket. In case the obstruction removal would not work at least the top ¾ cavern could be used for storage on time.

The planned gas completion was put in place, with the debrining tubing run in through the drilled hole and its tubing shoe set 2 m (6 ft) below the obstruction in preparation of future solution mining operation. First gas filling operation was successful. A sonar survey showed that no new rocks had fallen, although buoyancy had been reduced in the upper cavern part due to replacement of brine by natural gas. Now solution mining of the obstruction could start.

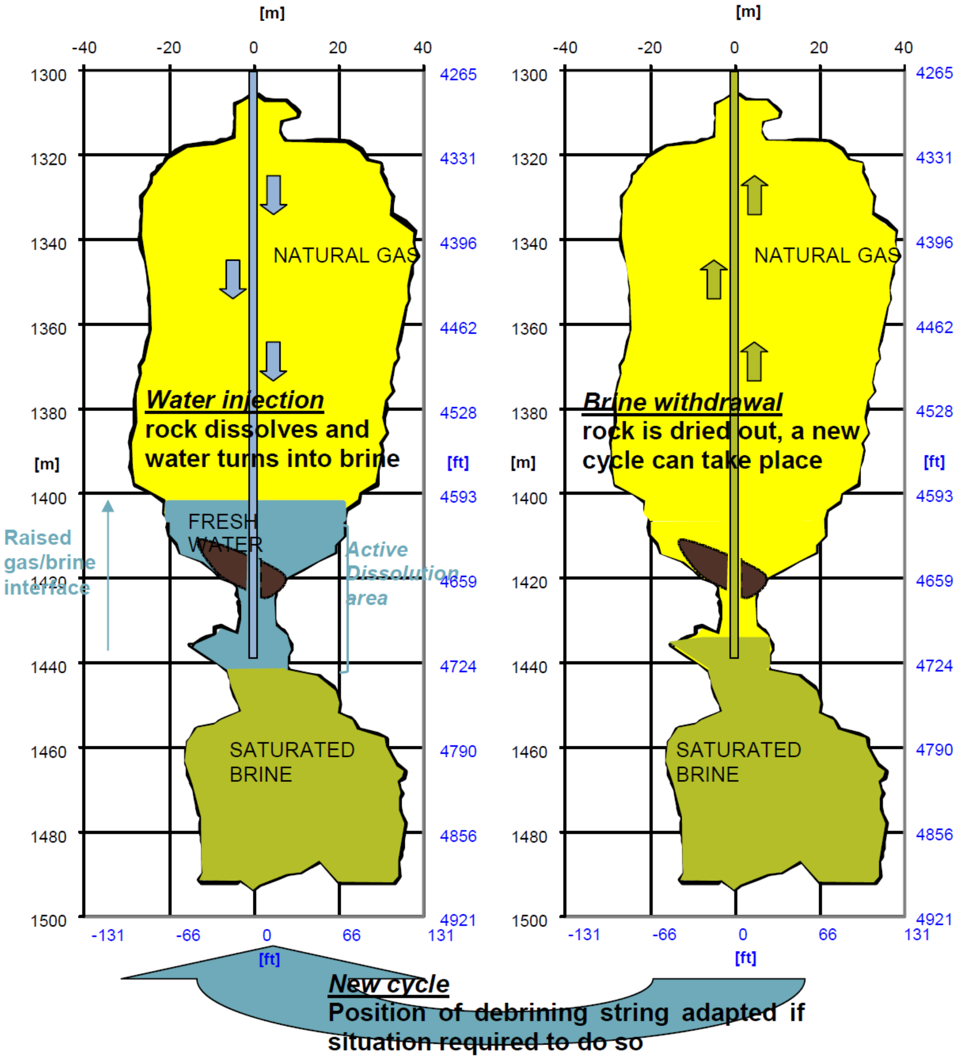


**String run into the hole previously drilled through the obstruction*

Fig. 8: Preparation operation before SMUG

2.3 Dissolving the obstruction.

For solution mining two tubes are usually needed: one for water injection and one for brine withdrawal. In this particular case, it was possible to use only one tube which would alternatively be used to inject water and withdraw brine. Water injection would raise the gas/blanket interface and injection would be stopped when the interface is above the obstruction. The brine withdrawal would lower the gas/blanket interface and withdrawal would be stopped before gas interface reaches the tubing shoe.



Water injection
rock dissolves and water turns into brine

Brine withdrawal
rock is dried out, a new cycle can take place

New cycle
Position of debrining string adapted if situation required to do so

Fig. 9: Solution Mining Under Gas

Less than 5,000 m^3 (42,000 barrels) of water had to be injected at each cycle, a small quantity compared to the huge gaseous blanket volume. The pressure of the compressible gas blanket would absorb the water/brine movement. No gas movement was necessary during the solution mining of the obstruction.

Several cycles were performed and the depth of the blanket interface regularly surveyed by logging tool. Afterwards a sonar survey was conducted to observe the effects. The sonar showed that the obstruction was no longer at the same place, but had slipped about 10 m (30 ft) down.

As the top of obstruction laid 4 m (12 ft) deeper than the tubing shoe, solution mining would have been inefficient at this stage. Furthermore the obstruction slipping had also moved the drilled hole and it could not be found anymore. Drilling another hole was not possible, as the upper cavern part was under gas.

2.4 Tail piping and snubbing

The last possibility to eliminate the obstruction was to inject water (from above) very close to it and count on the jet-effect to have water leach the obstruction. As the obstruction was 4 m (12 ft) away from the tubing shoe, the tubing would have to be lowered by 4 m (12 ft). Since the upper cavern part was under gas, leaching tubing movement would have required the use of a snubbing unit (which is both expensive and time consuming, see Fig. 10).

Typical costs for a snubbing unit

Mob/Demob:	~	130.0 k€
Operating costs:	~	2.0 k€/h
Standby costs:	~	1.5 k€/h

Fig. 10: Snubbing unit

Instead of having to move the pipe, it was (due to the relatively short distance of 4 m (12 ft)) possible to elongate it by adding a tail pipe at the bottom. This tail pipe consisted of just a short and smaller tubing which could be introduced into the well by wire line operation under pressure with a lubricator and set on the tubing shoe (see Fig. 11).

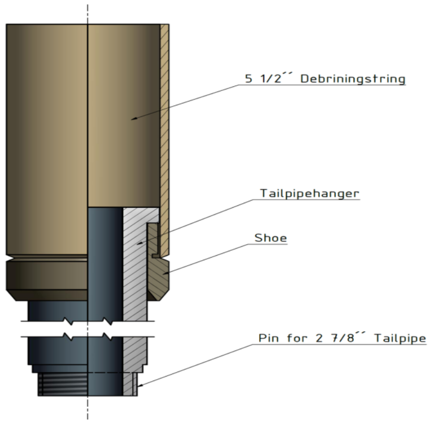


Fig. 11: Tail pipe extension

With the tail pipe put into place, water was injected at maximal rate in order to maximize the jet-effect. The tail pipe was then removed, brine withdrawn and the wire line measurement showed that a 2 m (6 ft) deep hole had been created in the obstruction. Tail pipes of 6 m (18 ft) and subsequently of 8 m (24 ft) length were successively set, thus allowing the “water drilling” of a new hole through the obstruction. The tail pipe operation proved to be fast and efficient.

By using a snubbing unit, the tubing was then lowered through the freshly “water drilled” hole so that the tubing shoe was set 2 m (6 ft) below the top of the obstruction. After a new leaching phase, a sonar measurement showed that the obstruction had been eliminated.

3 Results: cavern fully in gas operation

After elimination of the obstruction the tubing was lowered to the bottom of the lower cavern part by still using the snubbing unit. The first gas filling of the lower cavern part was then completed. Finally the debrining tubing was removed and the subsurface safety valve set in place. The full cavern was now filled with gas and operational for gas storage purposes.

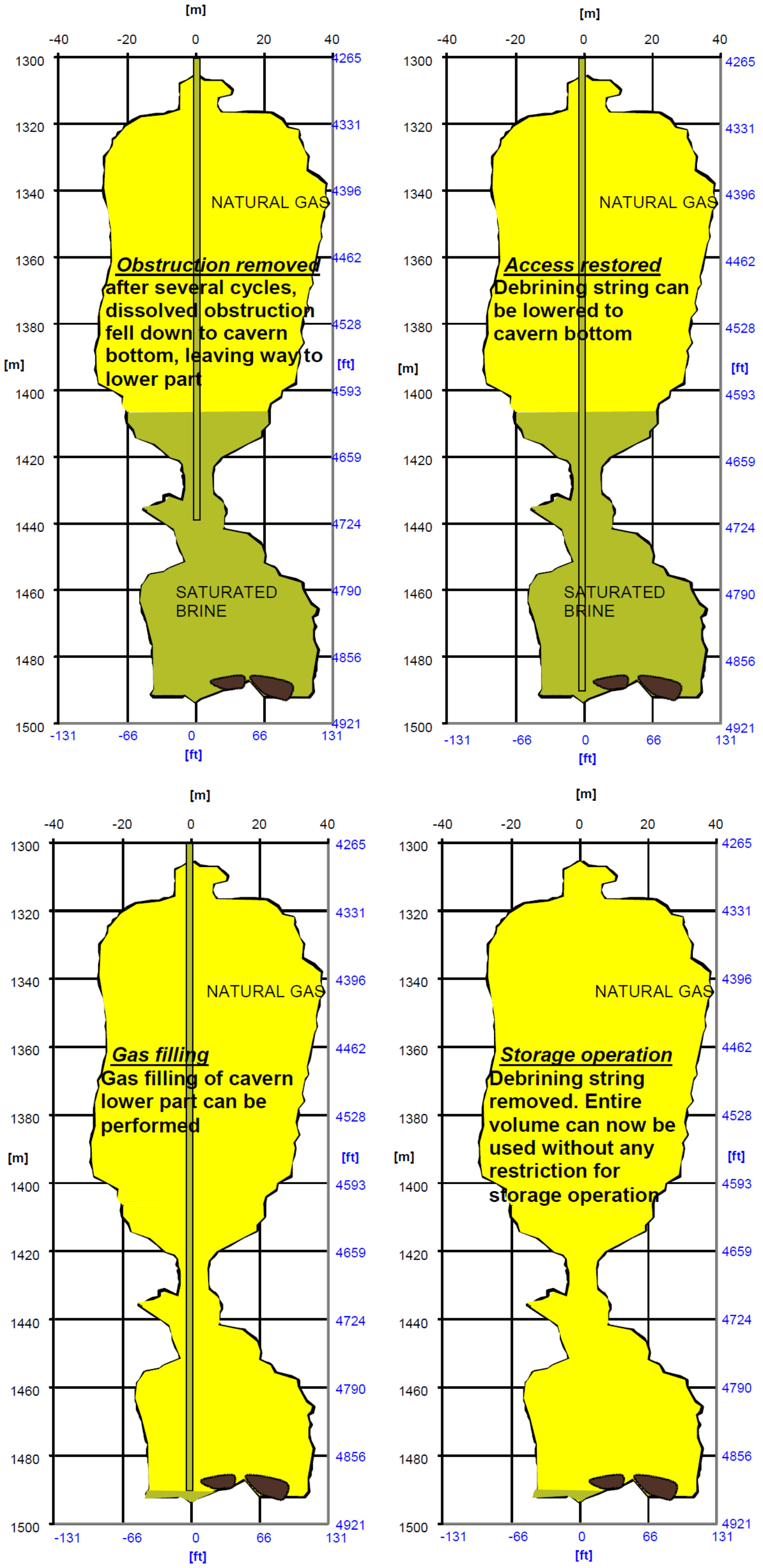


Fig. 12: Final works before storage operation

New and challenging problems were solved and contracted volumes delivered to the clients even under extremely challenging circumstances. The presented method successfully allowed avoiding the loss of the revenues corresponding to ¼ of the total cavern volume which were significantly higher than the implementation costs of these innovative techniques.

4 Conclusion

Storengy's and UGS's teams were confronted with major technical challenges during the development phase of Peckensen storage's cavern Ellenberg 2. This was mainly due to the unexpected occurrence of carnallite, a magnesium/potassium salt, dissolving several times faster than common salt (halite) and thus disadvantageous for cavern creation in terms of shape and volume.

Carnallite salt was found at planned mid cavern's height and detected at the well drilling stage. This called for a special cavern solution mining design: developing two cavern parts, one on top the other, with an 8-10 meter (26-33 ft) diameter link in between. This design and additional carnallite dissolution late in the development of the cavern created the uncommon case of an obstruction blocking access to the lower cavern.

Storengy together with UGS had to be creative as usual techniques would either be inefficient or potentially jeopardize the cavern's suitability for gas storage. Several delicate and/or innovative techniques (clearance of obstruction by dissolution, drilling through the cavern, SMUG with single pipe, tail pipes, "water drilling") were developed, designed and applied, under time pressure, in order to deliver storage capacity to the client.

Successful team work in a multidisciplinary context finally allowed the gas first-filling of the lower cavern part so that the entire cavern volume can be now used without any restriction for storage operation. Bringing together experts in the fields of solution mining, drilling and completion engineering or well-works as well as close exchanges between different entities of Storengy across two European countries on one side and experts of the engineering company UGS on the other side largely contributed to the successful design and implementation of these techniques. Lastly, as the working program had required nonstop adaptation to fit any bunch of new information coming out and thrown together with past records, all of it under heavy time pressure and unexpected situation changes, a step by step decision making process and an anticipative risk assessment proved to be key factors for the success of such operations.