SOLUTION MINING – EMISSION-FREE MINING OPERATION FOR A SUSTAINABLE UTILIZATION OF NATURAL RESOURCES

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ABSTRACT

The sustainable protection of natural resources is in times of rapidly increasing populations and a resulting shortage of agricultural land of existential importance. The resources of soil and groundwater have a central role for the production of food or feed of any kind. On the one hand, an intensive agricultural use must ensure sufficient income, on the other hand only a gentle as possible and environmentally friendly use of resources can ensure sustainable the life of future generations. Mining projects often represent a particularly deep intervention into ecosystems due to their size as well as the most expensive treatment processes.

Conventional mines comprising shafts and developed mining fields require the stockpiling of dead rocks and in particular in the potash mining the discharge of brines from raw salt processing. In contrast, mining operations based on the solution mining method can be operated without major environmental impacts and lower security risks. While the solution mining for production of rock salt is in application since more than 500 years, solution mining for exploitation of potash resources is used only since the 1980's. For solution mining drill holes are used for the exploitation of potash, which are launched from the surface into the deposit. The exploitation of the raw material is done by dissolution of the potash and the creation of so-called brine caverns.

Currently, a number of projects are under progress around the world to utilise Carnallite deposits by the solution mining method. Often these projects are located in sensitive ecosystems. KUTEC AG Salt Technologies supports currently a Chinese customer in a solution mining operation of a Carnallite deposit in South-East Asia. This order comprise a comprehensive geological and geo-mechanical modeling encompasses the necessary proof of stability, the planned cavern design and brine field layout as well as the planning of the brine processing and the plant design.

The present paper introduces this project as a case study. The application of a special solution mining procedure and processing design ensures an emission-free mining operation (Zero Disposal Plant). The emission-free operation is achieved mainly by a full usage of the caverns to dispose the liquid solutions from processing. The presentation of salt processing and technical equipment is supplemented and rounded off by information on the geology of the deposit. Since the deposit includes a number of sensitive minerals, such as Tachyhydrite and Bischofite, inside the presentation occur a lot of interesting items especially in view of preparation and operation of the brine field. K-UTEC designed and delivered a special blanket measuring system and a well cement according the request of the customer.

K-UTEC, a research and engineering company with more than 60 years of experience in the sector of potash and rock salt mining, developed the world's first solution mining operation for Carnallite in Germany more than 30 years ago. In recent times K-UTEC served different solution mining projects worldwide, with special view at the environmental impact, as well as the optimal utilization of the deposits.

KEYWORDS

solution mining, brine field layout, well layout, stability analyses, process design, zero emission plant, backfilling, well cement, blanket control system, Carnallite, Tachyhydrite, KCl, MOP

INTRODUCTION

In times of rapidly increasing populations and a resulting shortage of agricultural land the sustainable protection of natural resources is essential for future course of development. Especially the resources of soil and groundwater have a central role for the production of food or feed of any kind. On the one hand, an intensive agricultural use must ensure sufficient income, on the other hand only a gentle as possible and environmentally friendly use of resources can ensure sustainable the life of future generations.

Mining projects often represent a particularly deep intervention into ecosystems due to their size as well as the most expensive treatment processes. Conventional underground mines comprising shafts and developed mining fields require the stockpiling of dead rocks and in particular in the potash mining the discharge of brines from the raw salt processing. In contrast, mining operations based on the solution mining method can be operated without major environmental impacts and lower security risks.

While the solution mining for the production of rock salt for more than 500 years application finds, is the procedure for the production of potash using solution mining only since the 1980's years applied. For solution mining drill holes are used for the exploitation of potash, which are launched from the surface into the deposit. The exploitation of the raw material is done by the dissolution of the potash and the erection of so-called brine caverns. The brine product is removed to a surface processing plant for beneficiation of KCl and other by-products.

Currently, a number of projects will be developed around the world to utilize Carnallite deposits based on the solution mining method located often in sensitive eco-systems. The K-UTEC project and support currently for a Chinese customer of a solution mining operation of a Carnallite deposit in South-East Asia. The paper should introduce this project as a case study.

SOLUTION MINING – HISTORICAL ABSTRACT

Since immemorial times, the vital need for salt was covered by natural brine wells. In some regions with suitable salt deposits, the application of mining activities using so called “sunk works” or “Sinkwerke” are known amongst others. These “sunk works” are the origin of the solution mining operating with underground galleries and a lot of underground constructions. As basic principle serve the usage of water to dissolve the Salt components of the deposit via galleries and drifts, prepared before. The figure 1 should illustrate a “sunk work” of an Austrian mining in a cut section from about 1650. The development of this original technology leads to more sophisticated techniques using drill holes instead drifts and galleries and a blanket medium to control the leaching process. This technique is applied in a lot of salt mining operations worldwide.

While salt mining based on solution mining is widespread over the world, solution mining operations of potash are more sparsely applied. Especially solution mining for Carnallite as easy soluble salt mineral is much more demanding compared to salt production. Special dissolving regimes and composed solvents have to be used to run these operations safely and economically successful.

In the 1970’s the development of theoretically basics, laboratory tests and small scale tests begun at the former “Potash Research Institute” at Sondershausen/Germany. In the beginning of the 1980’s the production starts at the brine field “Kehmstedt” which is in operation since then and belongs now to the DEUSA International. The solution mining operation runs now for more then 30 years without significant technical problems at an annual capacity of 94,000 tonnes KCl and about 40,000 tonnes of Bischoffite. Due to the successful course, currently an upgrade program is running including increase of production capacity and expansion of the brine field.

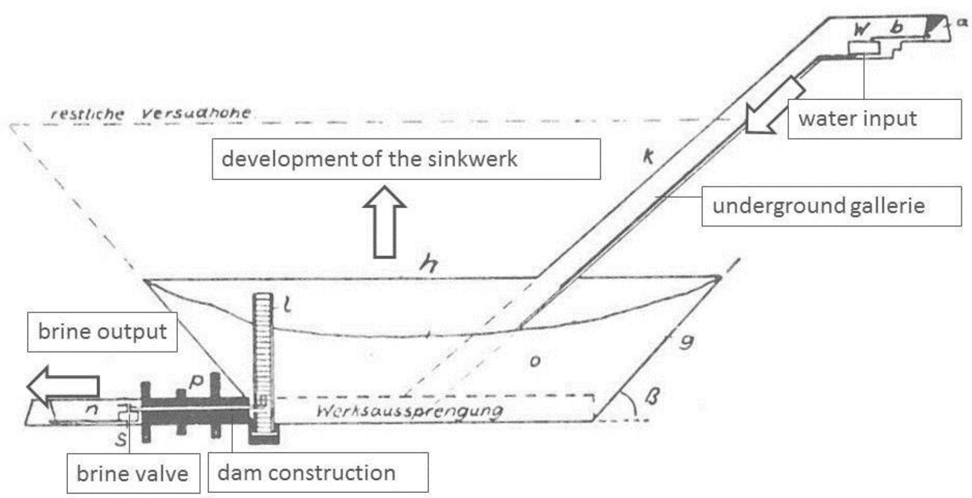

Figure 1 – Sunk work of an Austrian solution mining operation in a cut section from about 1650 (Eder 1949).

GEOLOGICAL SETTINGS AND LOCAL CONDITIONS

The evaporitic sequence is of Paleogenic origin and situated in a large expand depression area, filled mostly of continental sediments of Jurassic and Cretaceous age. At beginning Neogene, the tectonically forming of the structures intensified. By the elevation of the Phu - Phan - Uplift, the primary sedimentation area was divided into the southern Khorat - Basin and the northern Sakhon - Nakhon - Basin, reaching to Lao territory. The saline sedimentation is probable influenced by syn-sedimentary effects as a result of these tectonic movements (Punya et. al. 2007, Mantajit 1997). The figure 2 shows the location of the both basins.

The evaporitic comprise three salt forming cycles, two upper salt members of Rock Salt and potash bearing lower salt including the potash seam of Carnallite. The depth of the potash sequence varies between 400 m in the centre of the deposit and 100 m in the periphery areas. The potash layer is mainly of relative pure Carnallite including Halite and in some parts of larger Tachyhydrite and Bischoffite bearing zones. Tachyhydrite and Bischofite are most sensitive minerals for humidity and moisture and could influence the mechanically stability and hydraulically impermeability of the pillar structures strong.

The footwall of the potash seam is formed by a strong Rock Salt horizon serving as safety layer to the underlying lithological units. The middle Rock Salt above the mining horizon holds adequate thickness and lateral distribution to serve as safety layer to guarantee long term isolation against the overlying biosphere. The thickness of the Carnallite layer reaches up to 100 m in the central area of the deposit. The potash sequence can be divided principally into a lower part, consisting mainly of pure Carnallite with less amounts of Halite as the mine able part and an upper part containing partly Tachyhydrite and Bischoffite.

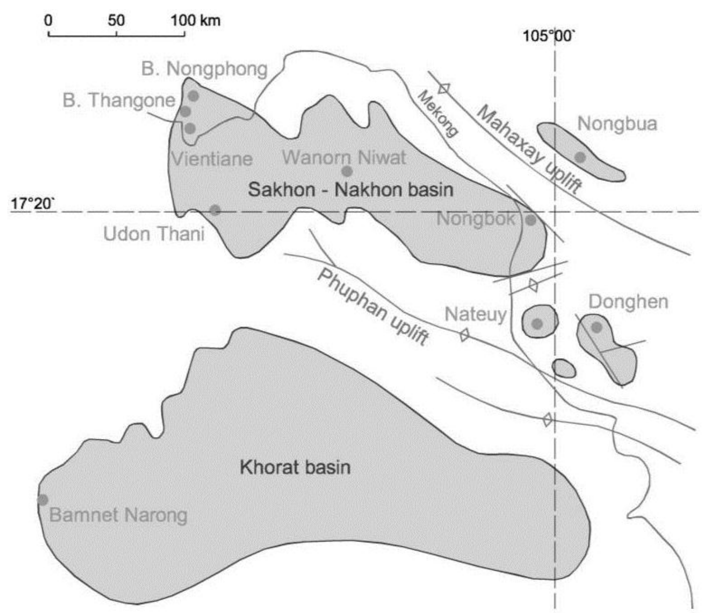

Figure 2 – Potash deposit location of the Khorat- and the Sakhon-Nakhon basin in northern Thailand and the PDR Laos.

STABILITY ANALYSES AND CAVERN DESIGN

For a safe mining operation without any negative effects for the biosphere and the integrity of the surface, an adequate geo-mechanical stability analyse of the cavern layout by using a numerical model as the standard procedure established in the world wide potash and salt industry is necessary. Such modeling considers commonly all relevant geological, hydrological and geo-mechanical conditions, like maximum depth of the cavern, the principal inclination and thickness of the potash layer, the mineralisation and the mechanical properties of the pillar structures and the barrier horizons.

To guarantee the function of the geological barrier horizons the following three criteria has to be fulfilled at any time during operation and after abandonment of the caverns:

- Minimum Stress Criteria (MSC),
- Dilatancy Criteria (DC),
- Maximum permissible strain, Aversin-Criteria (AC).

If these three criteria are complied on any time, the barrier horizon holds an undisturbed state and the function of the safety layer are ensured for long term conditions. According to proven criteria of the German potash mining industry, a safety layer above the caverns should be at minimum of 15 m thickness and below the caverns at 10 m thickness (Kamlot & Günther 1995).

The stability of the pillar structures between the caverns were evaluated according proven criteria and permissible loads and stress states (Minkley & Mühlbauer 2007, Kamlot 2009). With respect to the realistic simulation for the numerical modelling thermal effects and the influence of moisture was considered too (Plischke & Hunsche 1989, Wallner et. al. 1979). The figure 3 should illustrate the used principal model.

Due to the permanently brine pressure inside the caverns, the occurring subsidence on surface is in a very small range. The calculated influences of the surface, based on strictly conservative assumptions are significant lower than permissible influences according to proven German standards for subsidence control (Instruktionen Kombinat Kali 1982).

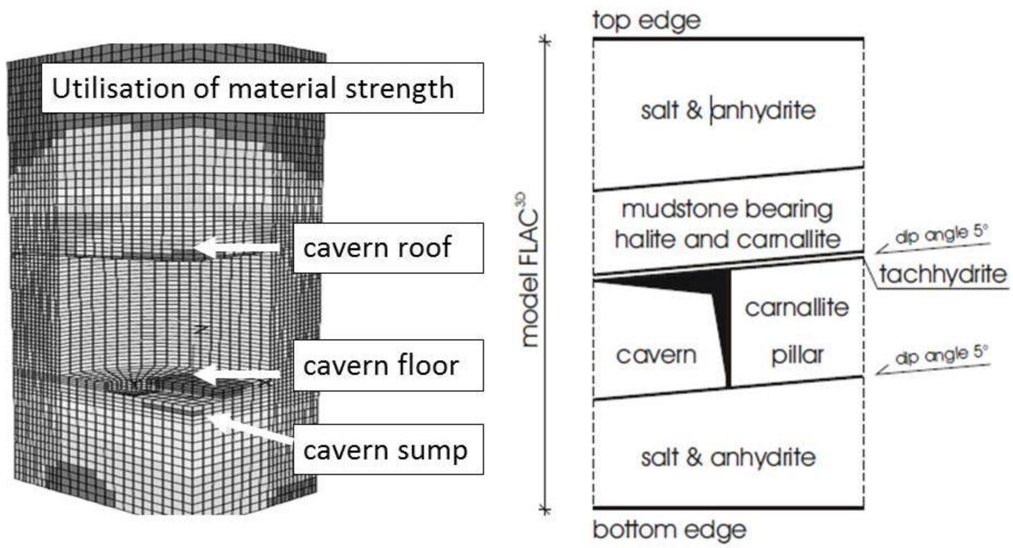

Figure 3 – Stability analyses using FLAC 3D code, the picture left shows a 3D-view of the utilisation degree of the material strength, the right side shows the principal model.

FIELD AND WELL-LAYOUT

Based on the stability analyses a suitable cavern design and field layout has to be developed. Figure 4 shows typical cavern design for single and dual wells applied for Carnallite solution mining. The final field layout should comprise furthermore the overall operation schedule for the mining operation according the geological conditions.

Beside the geometrical conditions of the caverns and the brine field the erection of the drill holes is a very sensitive issue. To run a stable leaching operation adequate casing installation is needed and has to be controlled. Since the deposit includes Tachyhydrite, a very sensitive mineral with equilibrium humidity about 16%, a special drilling and cementation procedure has to be established to avoid negative destabilisation effects. K-UTEC AG develops a special MgO-mortar for cementing the last casing inside the drill hole. This mortar is special adjusted to the sensitive Tachyhydrite bearing horizons and cover these area effectively. In principal the usage for cementing casings or special liner sections is possible.

To run the solution mining process a special measurement is needed to control the level of the used blanket compressed air. According the hard conditions inside the drill hole during the leaching operation, special designed strong equipment is necessary to guarantee the functioning of the system. K-UTEC develops a three electrode system based on proven technology from the DEUSA International, a solution mining operation for Carnallite in Germany. The blanket control system is completed as 6 5/8 tubing ready to install. The electrodes are of Titan in combination with Teflon to ensure a stable function.

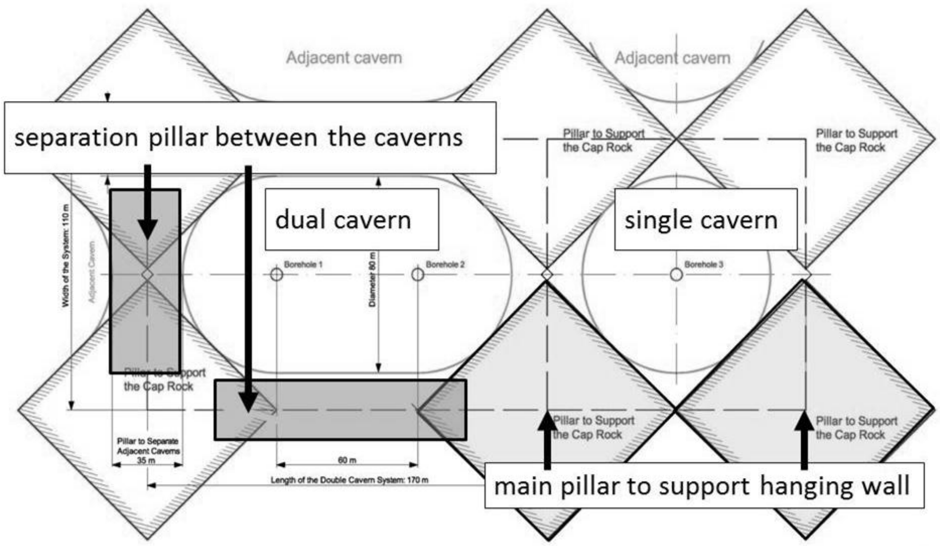

Figure 4 – Cavern layout of a dual well (left side) and a single well system (right side) including the main and the separation pillar structures.

SOLUTION MINING PROCESS

As first step is the drilling and completion of two drill holes needed. The completion of the drill hole has to be adequate to guarantee a stable and save structure during the leaching operation. The drill hole hit the whole potash sequence down to the foot wall. On the top of the deposit the last cemented casing shoe has to be fixed. For the occurrence of sensitive Tachyhydrite bearing horizons, the casing has to cover these structures to avoid dissolution effects within this geological structure.

For cementing the casing in sensitive Tachyhydrite bearing horizons, a special well cement is necessary to protect the sensitive layer and to guarantee the stability of the casing effectively. For this purpose, the K-UTEC has developed an MgO-based well cement especially for the application within this difficult geological conditions.

Between the cemented casing and the bottom of the drill hole inside the foot wall of the potash seam is an open hole, so the injection of water into the hole runs the solution mining procedure. In a first step occurs the so called sump leaching. The cavern sump should accommodate the insolubles of the deposit near the casings inside the well. For the leaching the sump, water is used in direct circulation. The solution of the sump is completed, if the diameter of the cavern has reached a diameter of about 4 – 5 m. To control the leaching process a blanket of compressed air is used. This blanket limits the dissolution upwards to the top of the potash seam and controls the development of the sump, undercut and principal cavern shape. To control the blanket level a blanket control system is in use to detect this level inside the well. For the special condition of the deposit, K-UTEC develops a special blanket control system of three Titan-electrodes and a temperature range up to 80°C. This system is based on a proven system of the DEUSA Company in Germany, operating since more than 30 years without significant problems.

The next step is the undercut phase. Water has to be injected by the outer tubing as indirect circulation. During this phase, the control of the volume stream and the blanket level is very important for optimized shape of the undercut structure. At the end of the undercut phase, the undercut section of the two well will be connected and the final ground area of the cavern will be formed. The figure 5 shows the principal solution mining procedure.

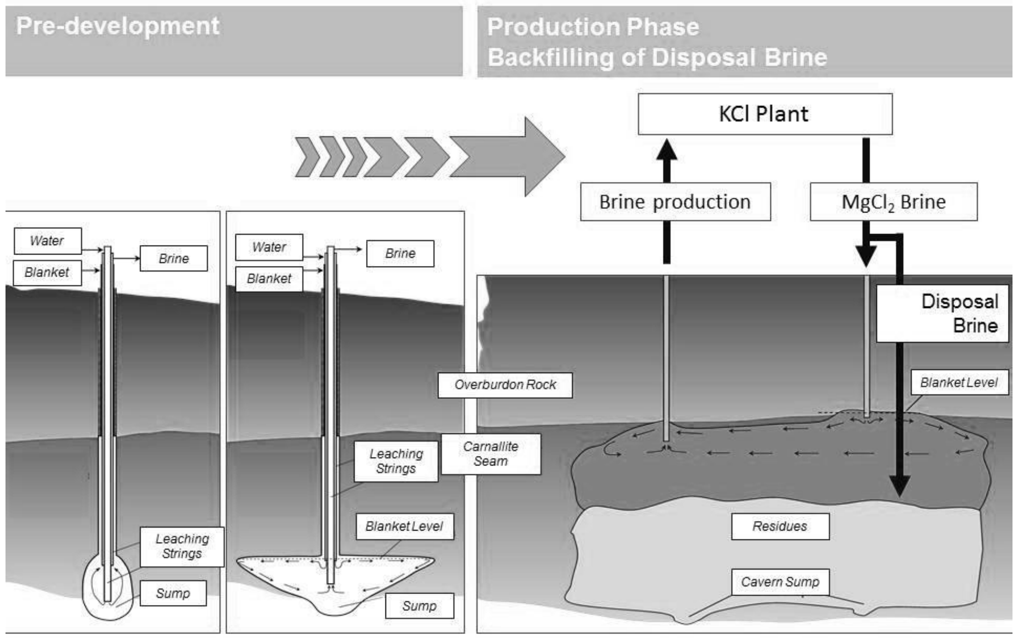

Figure 5 – Solution mining procedure with the sump and undercut phase on the left pictures and the production phase including the disposal of the waste brine on the right side.

After connection of both wells, the hot leaching operation begins as the production phase of the cavern. The so called hot leaching process could be realized only in double well caverns, due to the thermal heat exchange effects inside the wells. The level of the leaching string and the blanket has to be arranged higher as for the undercut leaching phase and the inner leaching string were removed complete. One of the wells serve as input hole and the other well accordingly output. When a salt volume with a determined deposit thickness was leached, the blanked level has to arrange in a higher position again and the current direction must be reversed. This operation with inversed current leads to better shaped caverns and higher deposit yield.

For hot leaching the solvent is hot $MgCl_2$ brine (about 70 … 90°C) - unsaturated of KCl and high saturated of NaCl. This leads to a selective dissolving or leaching of the raw salt. Carnallite with its constituents $MgCl_2$, KCl and 6 water is dissolved and NaCl only in such an amount that the solubility for NaCl is reached. Due to the $MgCl_2$ concentration increasing some NaCl will be re-crystallised and a big portion of the raw salt NaCl remains undissolved in the cavern.

The KCl saturation shouldn't be reached because otherwise KCl will be re-crystallised and the carnallite is decomposed. This is connected with additional KCl losses and a lower KCl yield. During operation stops of hot leaching caverns this effect cannot excluded because the dissolution process is running, the $MgCl_2$ concentration increases and it is possible that the KCl saturation is exceeded which is resulting in the mentioned disadvantages.

The fresh hot leaching brine flows through the input well into the cavern. The density of this brine is lower as the density of the brine in the cavern. This leads to a hydrodynamic lift of this brine and the density inside the cavern increases from the top to the bottom. Brine currents flow from the end of the input casing under the blanket level to the lateral cavern wall, which consists of soluble raw salt. Therefore the brine density becomes higher and it sinks down to a lower level and finally trough the output well to the surface. Leaching residues (mostly NaCl) sink to the bottom and remain in the cavern. By this way the residues becomes a stabilizing effect that means they influence the geo-mechanical stability of the cavern positively. The hot brine reach of KCl formed inside the cavern represents the base of the following KCl production, the KCl difference of the in- and outlet stream is one of the most important figures for the process efficiency.

The cold leaching procedure is suitable within single cavern systems in deposit parts with lower thickness. Cold leaching makes sense especially in combination with hot leaching caverns working with water as solvent. Therefore the leaching process is unselective, that means all soluble parts of raw salt are dissolved. $MgCl_2$ is in a range that KCl as well NaCl are completely soluble as important issue. The brine current and the general cavern shape are similar to the hot leaching caverns, only the amount of leaching residues is much lower.

The dissolved NaCl can be crystallized in the processing plant and finally sold as a by-product. This results in more space inside the caverns, available to store the disposal brine from the processing plant. By this way the volume balance is controllable and a zero disposal operation can be ensured.

During production phase, the backfilling of the disposal brine from salt processing takes place by using a second smaller tubing string inside the input well. The disposal should be realized by this tubing, ended in deeper parts of the caverns. So it is possible to bring the disposal brine below the zone of active salt dissolution. The exchanged hot brine is suitable for processing in the plant and means an additional KCL amount for the resource utilization.

After production phase and the complete filling by disposal brine it is necessary to close the boreholes and to re-cultivate the surface area for further usages. The closing of wells is based on a state of the art technology, similar to other well and drill hole operations. Finally the cemented casing were cut below surface and closed by melding so the drilling site could be re-cultivated.

BRINE PROCESSING AND POTASH BENEFICIATION

The leaching process in the underground caverns produces concentrated brine, which has to be treated in a processing plant to extract KCl from the brine and to produce marketable fertiliser grade potash. In a first step occurs the hot decomposition of Carnallite. The hot leaching brine, comes from the solution mining field, is used to decompose synthetic Carnallite, produced in a later process step. The decomposition process leads to crystallisation of a mixture of KCl and NaCl and the formation of $MgCl_2$-rich solution. The synthetic Carnallite, intermixed with some NaCl coming from the evaporation and crystallisation unit has to be fed back in counter-current stream. A principal flow sheet about the process is shown in figure 6.

From the decomposition reactor comes a suspension of KCl and NaCl and decomposition liquid, has to be separated into crystals mixture and brine. The clarified brine is led to a multiple effect evaporation plant. During the cooling process the mixture of synthetic Carnallite and NaCl will be crystallised. Solid salts, a mixture of synthetic Carnallite and NaCl have to be separated from the mother liquor and fed back to the decomposition unit. Carnallite mother liquor, as high concentrated brine with an $MgCl_2$-content of more than 420 g/l, is the base for synthesising the solvent liquid together with brine from cold leaching caverns.

A certain part of this Carnallite mother liquid has to be discharged to maintain the magnesium chloride and calcium chloride content in the processing liquid. The surplus of this solution has to be stowed in the “dead spaces” of the caverns as disposal brine. The amount of Carnallite mother liquor, which is not discharged, will be used as solvent brine in the solution mining process. After heating up is the solvent liquid in the hot leaching caverns.

The solids from the decomposition unit, a mixture of KCl and NaCl crystals, will be withdrawn as slurry from the thickener underflow and will be fed to a classical hot leaching process. In that process stage the differences in temperature dependency of solubility between KCl and NaCl will be used for a selective leaching of KCl. From the dissolver there will be withdrawn two different material streams. The first stream is the leaching residue, mainly consisting of NaCl crystals and the second stream is the hot leaching solution, almost saturated with KCl at present temperature. The crystallisation of KCl is carried out in a multiple stage flush cooling plant. After solid/liquid separation and drying this KCl salt can be sold as potash fertiliser.

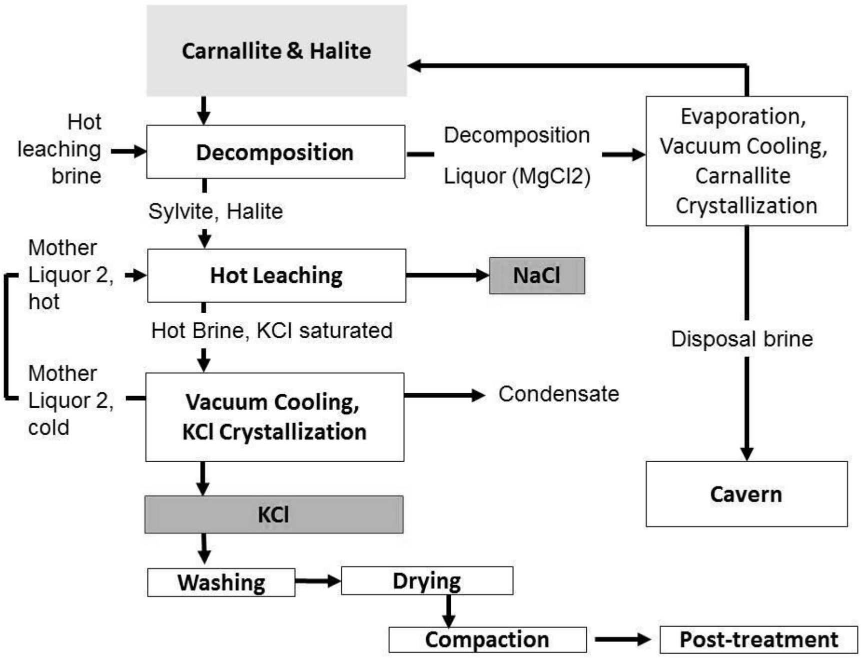

Figure 6 – Flow sheet of Carnallite processing from Carnallite and Halite as brine from the underground cavern to the final products KCl and NaCl as by-product and the disposal brine stored inside the cavern.

The total process of KCl production from hot solution mining brine requires a process plant with the following principal sections:

- Carnallite decomposition unit,
- Evaporation unit and Carnallite crystallisation,
- Solvent brine synthesis,
- $MgCl_2$ brine evaporation and $MgCl_2$ brine disposal,
- Hot leaching and KCl crystallisation unit, drying, storing and shipment,
- NaCl washing (or NaCl dissolving and re-crystallisation), drying, storing and shipment.

BACKFILLING – ZERO EMISSION OPERATION

The deposit of the case study is situated in urban area with agricultural usage. According these sensitive ecological basic conditions of the deposit location, it was necessary to design an environment-friendly mining operation and respective processing method. The solution mining procedure ensures a low impact for the surface, since the pillar system and the cavern layout base on save design. The infrastructure of the wells is mostly temporarily and can be re-cultivated after the cavern site will be abandoned.

To ensure a zero emission operation, the arising disposal brine from potash processing has to be stored within the underground caverns. The storage of the disposal brine occurs in the lower part of the production caverns, where the leaching process is finished. For the disposal of the brine special tubings are in use, so the backfilling runs during the cavern is in active production.

To reach a balanced operation without excess streams, the concentration of the disposal brine inside an evaporation unit is necessary. To get sufficient cavern volume able for storing the disposal brine, some of the cavern operating in cold solution mode. The extracted NaCl resulting from the non-selective leaching process of cold leaching procedure could be sold as by-product. By this way the management of the process streams is possible and the zero emission operation can be ensured (Bach, Kaps & Scherzberg 2012). The key for success are a special schedule for brine field development and a brine field regime with distinct ratio of hot and cold leaching caverns.

CONCLUSIONS

The application of solution mining procedure for the extraction of Carnallite is state of the art, designed and developed by the former Potash Research Institute, a precursor of the K-UTEC AG Salt Technologies. The first solution mining operation for Carnallite worldwide at Kehmstedt-deposit in Germany is now in operation for the last 30 years without significant problems resulting in a lot of experience about this special mining method.

For Carnallite mining in areas of sensitive eco-systems, solution mining is mostly the only suitable and applicable method that meets the governmental requirements. The solution mining procedure is a save method since cavern design and field layout are based on proven standards. A zero emission mining operation is possible using a special schedule for brine field development and brine field regime with hot and cold leaching caverns. By this way the utilization of resources in urban or ecological sensitive areas is possible without negative effects for the environment, ensuring a high utilization rate of the mineral resource.

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