INTRODUCTION

Since the first potash fertilizer production started in 1861 in the Stassfurt region (central Germany), the worldwide annual production has increased up to over 25 million tons of K$_2$O in the last three decades. The need for food supply for a growing world population will necessitate a further increase of fertilizer production in the future. That requires strategies for the reduction of these environmental impacts too. A reduction of both the surface subsidence and the disposal of residues at the surface is possible by backfill of the mine openings, as realised in some mining districts since the early years. In this connection the slurry backfill technology (in German: Spülversatz) posses remarkable advantages and may upgrade the economics of potash production.

ABSTRACT: Potash fertilizer production from underground extracted ore is compound with a relative high amount of solid and liquid waste materials and with surface subsidence above the mines. Commonly, the solid residues are stored on tailings piles at the surface and the disposal brines are injected in the underground by wells. The need for food supply for a growing world population will necessitate a further increase of fertilizer production in the future. That requires strategies for the reduction of these environmental impacts too. A reduction of both the surface subsidence and the disposal of residues at the surface is possible by backfill of the mine openings, as realised in some mining districts since the early years. In this connection the slurry backfill technology (in German: Spülversatz) posses remarkable advantages and may upgrade the economics of potash production.

1 INTRODUCTION

Since the first potash fertilizer production started in 1861 in the Stassfurt region (central Germany), the worldwide annual production has increased up to over 25 million tons of K$_2$O in the last three decades. The need for food supply for a growing world population will necessitate a further increase of fertilizer production in the future.

Unlike to other mining branches, decreasing ore reserves do not limit the growth of potash fertilizer production. The economy of potash ore extraction and processing in the classical mining districts is strongly influenced by operational and transportation costs, more than by geological parameters. Important influencing factors result from the environmental impact of the underground extraction and the ore processing. In the case of underground mining extraction, this impact is mainly determined by solid and liquid processing residues at the surface and the time-dependent subsidence of the surface above the mines (for example see Bodenstein et al., this volume).

During the last decade, some potash producers have reduced these effects step-wise by several activities. For example, in the Werra Production Centre of the unified German Potash Industry, the salt content of the river Werra was reduced by introduction of modern processing technology after Germany’s political re-unification.

In general, a further reduction of the environmental impact is possible by a more efficient waste management coupled with consistent backfill of the extraction rooms. This technology reduces both the tailings piles at the surface and the surface subsidence above the mines. Firstly, this contribution will explain the processing technologies on two common examples and their control by the ore quality, respective the chemical composition of the ore. Secondly, we will illustrate the mass and volume balance between mine openings and residues. Finally, we will discuss the positive effect of the slurry backfill technology on both the environmental impact of potash processing as well as the economics of potash mining.
Modern potash production is not simply an extraction and processing business alone. The environmental impact and the economics of modern potash production as well, are strongly influenced from the tailings and disposal brine management. The reason behind this comes from the chemical, respective mineralogical composition of the potash ore.

This fact should be explained by the following figures: the most important potash mineral is sylvite (KCl) with an mineral K₂O content of 63.2 mass percent, followed by carnallite (KCl x MgCl₂ x 6 H₂O) with an mineral K₂O content of 16.9 mass percent. Potash deposits around the world contain sylvinitic and/or carnallitic crude salt with K₂O contents in the range from 8 up to 30 mass percent. These figures illustrate the amount of waste material, which is separated from the potash components by mineral salt processing, e.g. hot by leaching and/or flotation of the extracted crude salt. These processing residues are liquid (disposal brine) and solid (tailings). Their specific amount per each ton of product depends on the mineralogical composition of the crude salt and/or the processing technology, and will illustrate by two examples:

Example A (Fig. 1a) is a low-grade carnallitic ore with an average K₂O content of 9.0 mass percent from a sulphate-type deposit (e.g. Zechstein 2, Germany). The main component and the ore mineral is carnallite. The sulphate minerals are kieserite (MgSO₄) and anhydrite (CaSO₄). Additionally tachyhydrite (CaCl₂ x MgCl₂ x 12 H₂O) occur also. The normative sylvite content is zero.

Example B (Fig. 1b) is a high-grade sylvinitic ore with an average K₂O content > 22.0 mass percent from a chloride-type deposit (e.g. Russia, western Canada, north central Thailand). The main component is halite. The ore minerals are sylvite and carnallite. Small amounts of unsolvable clay material and a small brine content in the pore volume occurs in both ores.

The main differences of these ores are given by the percentage of valuable material (K and/or Mg) and waste material, in general shown by the K₂O content, and by the mineral bound water content. These differences are shown by the chemical compositions (Fig. 2). According these differences the processing for both ores needs different technological steps. The main technological step to extract the valuable potassium content are described briefly in the following subchapters.

### 2.1 Hot Leaching for the Processing of Low-grade Carnallitic ore

This process requires an complete dissolution of the crude salt by aqueous solution. The result of the first processing step, the dissolution process himself, and the following cooling and crystallisation is KCl and a mother liquor, for this example here it contain 52 g/l of KCl and 292 g/l MgCl₂ as main chemical components. Evaporation of the surplus of the mother liquor by an further processing steps leads to the crystallisation of the valuable potassium as artificial carnallite. The final product results from decomposition of this carnallite. Residues of this processing are 288 m³ wet solids with an high pore volume and 399 m³ disposal brine per 1000 tons of processed carnallitic ore.

<table>
<thead>
<tr>
<th>Disposal brine (g/l)</th>
<th>KCl</th>
<th>NaCl</th>
<th>MgSO₄</th>
<th>MgCl₂</th>
<th>CaSO₄</th>
<th>Other</th>
<th>H₂O</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet solid residues (kg/t)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine-grained</td>
<td>7.5</td>
<td>63.1</td>
<td>21.3</td>
<td>11.9</td>
<td>5.0</td>
<td>4.7</td>
<td>38.5</td>
<td>151.8</td>
</tr>
<tr>
<td>Coarse-grained</td>
<td>3.9</td>
<td>185.6</td>
<td>62.5</td>
<td>8.5</td>
<td>14.9</td>
<td>14.1</td>
<td>45.4</td>
<td>334.8</td>
</tr>
</tbody>
</table>
2.2 Flotation for the Processing of High-grade Sylvinitic ore

The backbone of this processing technology is flotation. The separation starts after repulping of the crushed crude salt with process brine and leads to a KCl enriched concentrate and flotation residues. Leaching by water effect an enrichment of KCl up to the final product. This leaching water and further water sources leads to a surplus of processing brine which should be disposed. In our example, the amount of disposal brine is 268 m³ per each ton of processed sylvinitic ore and the amount of wet solid flotation residues with an high pore volume is 494 m³ per 1000 tons of processed sylvitic ore.

3 BALANCE OF EXTRACTED ORE VOLUME AND PROCESSING RESIDUES

The mass and volume balance between extracted ore, products and residues is shown in Fig. 3. At first, the figures show that the amount of product is relative small compared with the amount of wet and liquid waste material. These relations are strongly controlled by the quality of the ore. The comparison of both processing technologies shows that the amount of disposal brine is higher for the carnallitic ore, as expected in respect to the chemical composition. The amount of wet solid residues is higher for the sylvinitic processing by flotation. In both cases the solid residues are wet and contain absorbed brine from the processing. The pore volume of these processing residues is in the range from 40 up to 55 percent and depends from the grain size and the grain size distribution.

These figures illustrate too that the volume of the extracted ore in the mine is much more smaller than the sum of the final potash product and the different waste materials. Because processing needs additional water and leads to a decomposition of hydrate minerals the volume of the solid residues and the disposal brine is also larger than the volume of the extracted ore. The high and mainly air-filled pore space of the wet residues cause the large volume of the initial tailings. In case of the high-grade sylvite processing this initial residue volume is larger than the volume of the extraction rooms in the mine. For these reasons, present potash production needs tailings piles for the wet solid residues and underground injection wells and/or other solutions for the disposal brine problem.

4 RE-USE OF PROCESSING RESIDUES AS BACKFILL MATERIAL

Re-use of tailings for backfilling the extraction rooms started in the early years of potash industry by use of dry and wet residues. Different technologies are developed during the last 80 years. One of these, the slurry backfill technology (in German: Spülversatz) is a very efficient backfill method, because of its combination of tailings and brine disposal.

Since 1908 a special hydraulic backfill technology was adapted from the Upper Silesian coal mines into the young German potash industry. Since this time, the slurry backfill technology has been successful practised in the German potash industry, especially in flat-lying deposits of the South Harz potash district.

In slurry backfill technique the waste product of potash processing (e.g. halite and anhydrite) is mixed with a flushing brine and reintroduced as backfill in a liquid form into previous mine rooms. The flushing fluid comprises residual brine that is also a by-product of the processing of the crude salt and acts as the transport medium for the solid crystalline tailings. The hydraulic transport of this slurry backfill is accomplished via a pipeline system from the surface to the backfill panel where the gravitational potential energy of the introduced medium ensures its transport.

Experience from working simple slurry backfill facilities shows that in a routine mine environment with a vertical height difference of 600 m, transport over 5 km is possible. For transport to the further reaches of the mine system then a pump system needs to be installed to overcome pipe friction. In general, the horizontal transport distance without additional pumps is 8 ... 10 times more than the geodetic difference.
Fig. 3: Mass and volume balance between extracted ore, final potash product, solid and liquid waste material for hot leaching of low-grade carnallitic ore (a) and flotation of high-grade sylvinitic ore (b)
A turbulent flow within the pipeline system avoids the settling of the solids out of the slurry mixture and any gravitational sorting of the solid material and ensures that the quality of the backfill slurry remains constant during transport (Fulda 1966). The introduction or stowage of the backfill is achieved by an inclined build-up in the dip direction. The further lithification of the backfill is achieved through the gravitational separation of the solid from the brine. When the flow velocity of the slurry slows to a critical point, the solid material then sinks. This results in a simple sorting in a horizontal direction.

The density of the backfill body is dependent upon the waste solid material used and the on-site condition of the mine rooms. For the waste tailings of the high-grade sylvinite ore a density higher than 1.80 t/m³ is expected. This density is usually achieved after several hours to days after introduction of the slurry backfill, dependent upon local working and/or geological conditions.

The lithification of the backfill body is also dependent upon the amount pore space reduction, and more importantly the crystallisation of surplus brine within the pore space. As this is time dependent, the backfill body reaches its maximum lithification only after a significant time period. In situ measurements indicate that in a routine working environment the maximum lithification of the introduced backfill is reached after few weeks to months, and is 50 to 75 % the original density of the originally mined potash and rock salt.

The backfill body is further compressed by convergence, leading to increased lithification. The time period until the slurry backfill approaches the strength of the originally mined material is determined from the convergence rate. Experience form the eastern German potash industry indicates that the strength after 3 months is approximately the same as the natural strength of the surrounding potash salt rocks.

Early slurry backfill installations, created to allow the re-use of residue from German Hartsalz (sylvinite + halite + anhydrite) processing, produced backfill densities over 1.90 t/m³. High-grade sylvites contain lesser anhydrite than Hartsalz. Due to this lower anhydrite content, the density of the backfill in a high-grade sylvinite mine will be less, probably over 1.85 t/m³. The stowage capacity (degree of filling) is dependent upon from the morphology of the excavated rooms and varied in German mines between 85 % and 98 % as average value for the whole backfilled panels.

5 ADVANTAGES OF SLURRY BACKFILL TECHNOLOGY

The comparison of the material parameters of dry or paste backfill and slurry backfill shows that the first technology is not so efficient in sense of tailings and disposal brine reduction. The dry backfill method involves the stowing of artificially dampened residues into previous mine rooms. The transport of such backfill material requires a system of conveyor belts stretching from the mine head to the area being backfilled. The stowing of the dry backfill to within 15 cm of the mine rooms roof is performed using flingers. The degree of filling of the extraction rooms is up to 90 % under good geometrical conditions. The in place the density of this backfill is about 1.36 t/m³, for example of the flotation residues from a high-grade sylvinite.

The figures shown in Table 2 express the better efficiency of slurry backfill technology from the volume-mass balance point of view, which is mostly important for the environmental impact. That means, a larger amount of residues can be deposited in the mine openings by slurry backfill technology than by dry and/or paste backfilling.

Advantages on the rock mechanical effect of backfilling comes from the higher mechanical strength of slurry backfill as discussed by Bodenstein et al. (this volume) in detail. This property is induced by the solidification of the slurry material which is realised by sedimentation of residual fragments from the suspension and the crystallisation of new solids in pore space from the brine. Both processes produce an artificial salt rock, which shows mechanical and hydraulic properties like or better the natural salt deposit (Rauche & Mierdel 1999, Eulenberger 1999).
Table 2: Main differences between slurry and paste backfill technology, based on the calculations for residues from flotation of high-grade sylvinitic ore

<table>
<thead>
<tr>
<th></th>
<th>paste backfill material (t/ m³)</th>
<th>slurry backfill material (t/ m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-place density</td>
<td>1.36</td>
<td>&gt; 1.80</td>
</tr>
<tr>
<td>Moisture content</td>
<td>6 wt %</td>
<td>5 wt %</td>
</tr>
<tr>
<td>Brine handling</td>
<td>open system</td>
<td>closed system (circuit)</td>
</tr>
<tr>
<td>Transport technology</td>
<td>open conveyer belts</td>
<td>closed pipes</td>
</tr>
<tr>
<td>Stowing rate</td>
<td>up to 15 cm under roof</td>
<td>&lt; 90 %</td>
</tr>
<tr>
<td></td>
<td>80 to 95 %</td>
<td></td>
</tr>
<tr>
<td>Stowing technology</td>
<td>flingers</td>
<td>pipes and dams</td>
</tr>
</tbody>
</table>

6 SUMMARY AND CONCLUSIONS

The slurry backfill technology can contribute to an reduction of the environmental impact of potash fertilizer production by two different ways: (i) The higher degree of filling, the higher density, compared with dry and/or paste backfill, and the brine-filled pore space leads to a better utilization of the mine openings by backfilling and to a reduction of tailings and/or disposal brine at the surface. (ii) The higher degree of filling paired with the higher mechanical strength of the slurry backfill body in the mine openings reduce the surface subsidence above the mines.

Furthermore, the positive rock mechanical influence of the slurry backfill material allows a reduction of the extraction losses by

- smaller pillar sizes during the primary mining phase
- pillar re-extraction during a secondary mining phase

without any risk of surface subsidence and/or instability of the mine. Both, the reduction of the tailings and brine disposal at the surface and the higher extraction ratio influence the economics of the production by lower overall operating costs and/or longer lifetime of the resources.

REFERENCES

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