

THE PRODUCTION OF ROCK SALT PRODUCTS FROM ALPINE DEPOSITS BY PHYSICAL PROCESSING TECHNIQUES

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Abstract

For a few years the demand for rock salt products used as so called "natural salt products" has been rising. Health food shops and drugstores are offering these salts for various uses – e.g. table and bath salts. The Austrian salt deposits at the Eastern Alps exhibit – due to intensive rock faulting processes – a strong intergrowth with the surrounding gangue minerals. Therefore, a direct use of rock salt from these deposits is not possible. The aim of this research cooperation between the Salinen Austria AG (SAAG) and the Institute for Mineral Processing was to identify the possibilities and limitations of the production of rock salt products from these alpine deposits by physical processing techniques.

The following quality-related parameters were defined regarding rock salt products:

- Optical uniform appearance, i.e. as free from dark impurities as possible
- Soluble fraction > 97 %
- Suitability as edible
- Flowability
- $k_{\max} < 6 \text{ mm}$

Various difficulties made the use of wet processing techniques impossible. Therefore, only dry processes were analysed and only the following three processes were actually tested:

- Optical Separation

The tests demonstrated clearly that an upgrading is possible due to the wide differences in colour. However, this technique may only be used as a pre-upgrading process, because the processable particle sizes are about 3 mm and a satisfactory liberation occurs at particle size smaller than 3 mm.

- **Magnetic Separation**

The X-ray-diffraction-analysis reported the occurrence of paramagnetic minerals in the raw material (breunerite, chlorite, iron oxides).

The magnetic separation tests demonstrated that this technique can be used to separate gangue and salt minerals. Mass yield and the soluble content could be improved with decreasing particle sizes. The required soluble content of more than 97 % could be achieved with particle sizes between 1/0.5 and 0.5/0.1 mm.

- **Electrostatic Separation**

The tests were to check if the differences in the conductivities of the minerals can be used for separation.

By electrostatic separation the mass yield and the soluble content could be improved with decreasing particle sizes as well. Thereby, particle sizes of 2/1 mm already contained the required percentage, and particle sizes of 1/0.5 mm contained more than 98 % of soluble material. However, the percentage in the smallest particles (0.5/0.1 mm) decreased considerably.

The results in electrostatic separation became worse with decreasing particle sizes, whereas in magnetic separation this would happen with increasing particle sizes. Hence, a combination of magnetic and electrostatic separation balanced the particular weaknesses of each process. Thereby a quality-compliant product with more than 98 % soluble material could be achieved with particles between 2 and 0.1 mm in size.

1 Introduction

Sodium chloride (NaCl) has been mined from alpine deposits in Austria for more than 3,000 years. Formerly, mining was accomplished in two ways: On the one hand, the salt was mined underground and the miners followed the salty layers into the mountain, on the other hand, brines of lower grades were collected on the surface.

Nowadays, sodium chloride is mined exclusively by solution mining in Austria, because of the strong intergrowth between salt and gangue minerals. By this procedure, two phases are formed: First, the solid phase, consisting of the insoluble residue, called "Laist", which remains in the caverns and the borehole wells. Second, the liquid phase, consisting of the (raw) brine, which will be processed in the salt purification plant to evaporated salt by extracting the calcium,

strontium, magnesium, lithium, carbon trioxide and sulphate ions and evaporating the brine in crystallizers. The resulting sodium chloride is a very pure and fine-grained salt product.

For a few years the demand for rock salt products – particularly as table salts – has been rising. Health food shops and drugstores are offering these salts – partly transported for long distances – using various trade names, e.g. Natural Salt, Primal Salt, and Himalaya Salt.

Therefore, the company "Salinen Austria AG" (SAAG) planned – in a corporation with the Institute for Mineral Processing – a research project concerning the production of rock salt. The first task was to analyse the possibilities of physically processing the rock salts from alpine deposits. And the second task was to

ascertain if the demand for those products can be covered by the use of domestic deposits.

This publication covers the mostly experimentally gained results and the possibilities and limitations of physically processing rock salt from alpine deposits.

2 Genesis of the deposits

The salt deposits, mined by the SAAG, are part of the saliniferous formation in the Eastern Alps. This formation is about 350 km long and as broad as 35 km from Hall in Tyrol to Heiligenkreuz close to Vienna. This deposit

was generated in two epochs and stages, respectively: from Lopingian (Permian) to Induan (Triassic) and from Olenekian to Anisian (both Triassic).

In Triassic and Neogene the rock faulting processes caused the salt layers to form diapirs, typical for the saliniferous formation in the Eastern Alps. This transformation leads to impurities in the deposits. The resultant mixture of minerals contains halite, gypsum, anhydrite, various other salts – e.g. potassium and magnesium salts – and clay minerals. It is called Haselgebirge Rock.¹

Figure 1 displays the salt layer (pink) and its intergrowth with gangue minerals (dark) very clearly.

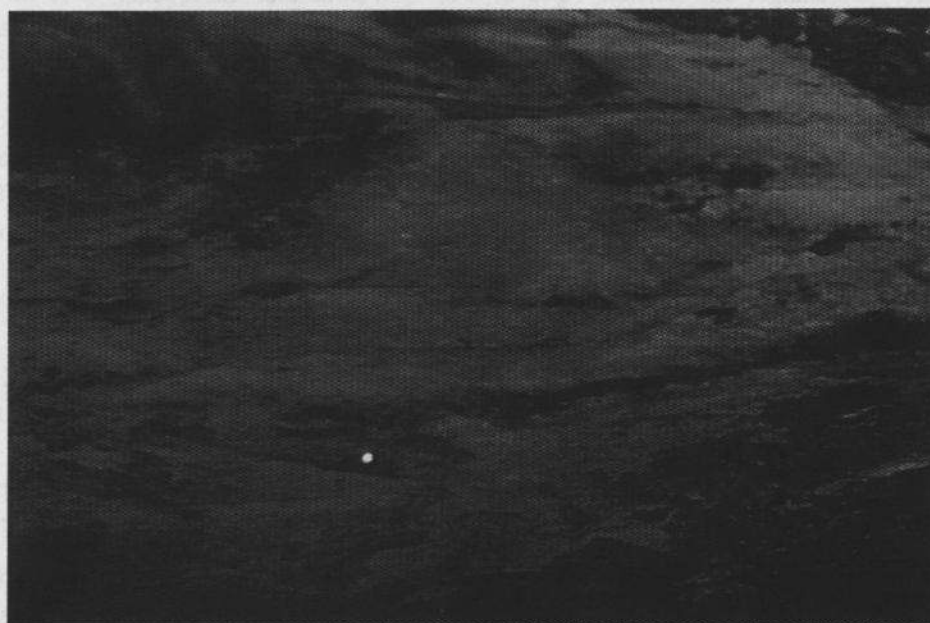


Figure 1: Salt layer crossed by gangue minerals

2.2 Brief outline of the current salt production in Austria Rock salt and all other accompanying salts are, together with hydrocarbons and uranium and thorium containing mineral resources, assigned to the so-called “federally owned mineral resources” by the Austrian Mining Law. The SAAG is authorized by law to explore, mine and appropriate the rock salt with all accompanying salts.

At present, solution mining of the SAAG is carried out at three locations: two underground operations in Altaussee (40 % of the production) and Hallstatt (30 %) and one surface production in Bad Ischl (30%).

The brine is pumped to the salt purification plant in Ebensee, where it is thermally processed to evaporated salt (figure 2).

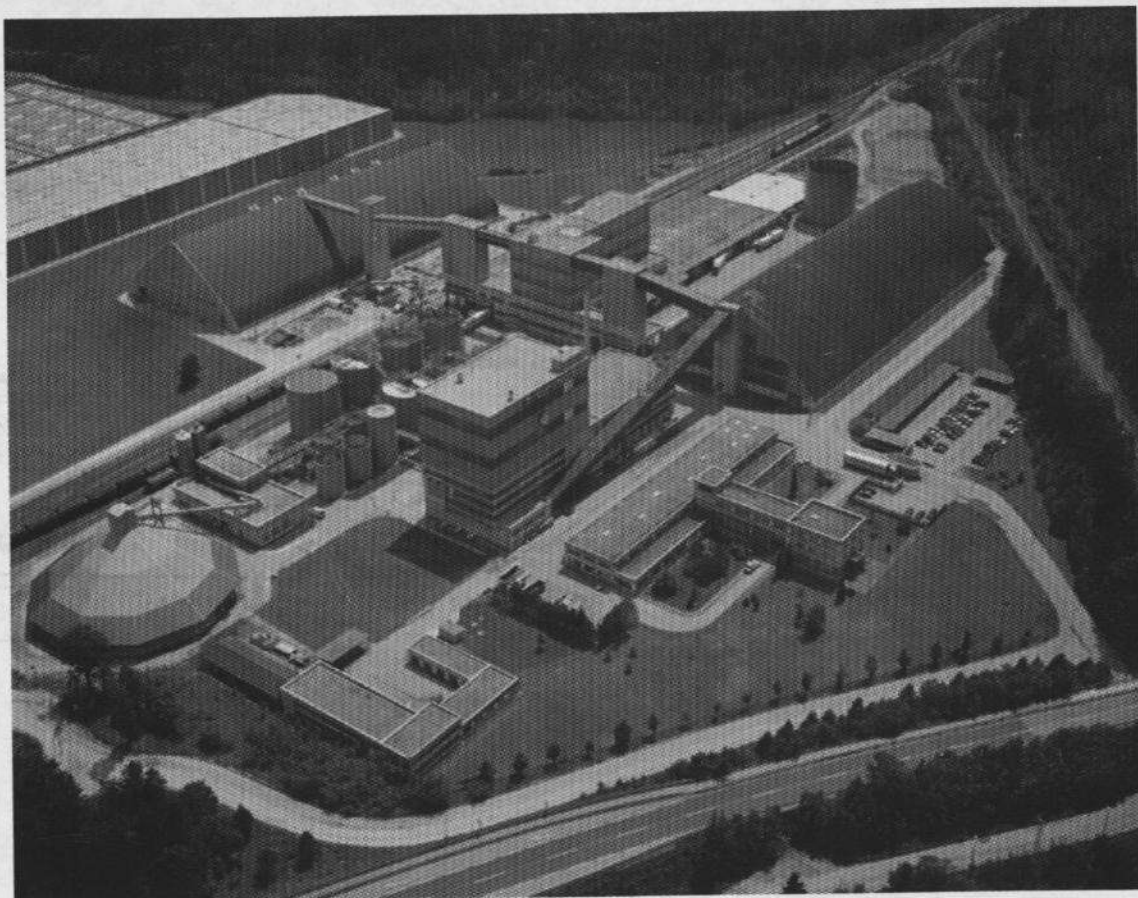


Figure 2: Photograph of the salt purification plant of the SAAG in Ebensee

The extracted brine is deionised by the Schweizerhalle process and then evaporated and crystallized by the thermal compression process. Nowadays, about 2,500,000 m³ of brine are processed in the salt purification plant, resulting in a production rate of sodium chloride of about 750,000 tonnes.

The by-products of the salt processing – the residues of the Schweizerhalle process and the mother liquor – are used as follows: The

residues are mostly used as a backfill in the surface operations in Bad Ischl as well as in the underground works in Altaussee. The mother liquor is processed in a worldwide unique process, where about 70 kg of K₂SO₄ and 340 kg of NaCl is produced per m³ of mother liquor.

Figure 3 displays a simplified outline of the process “from brine to evaporated salt”.

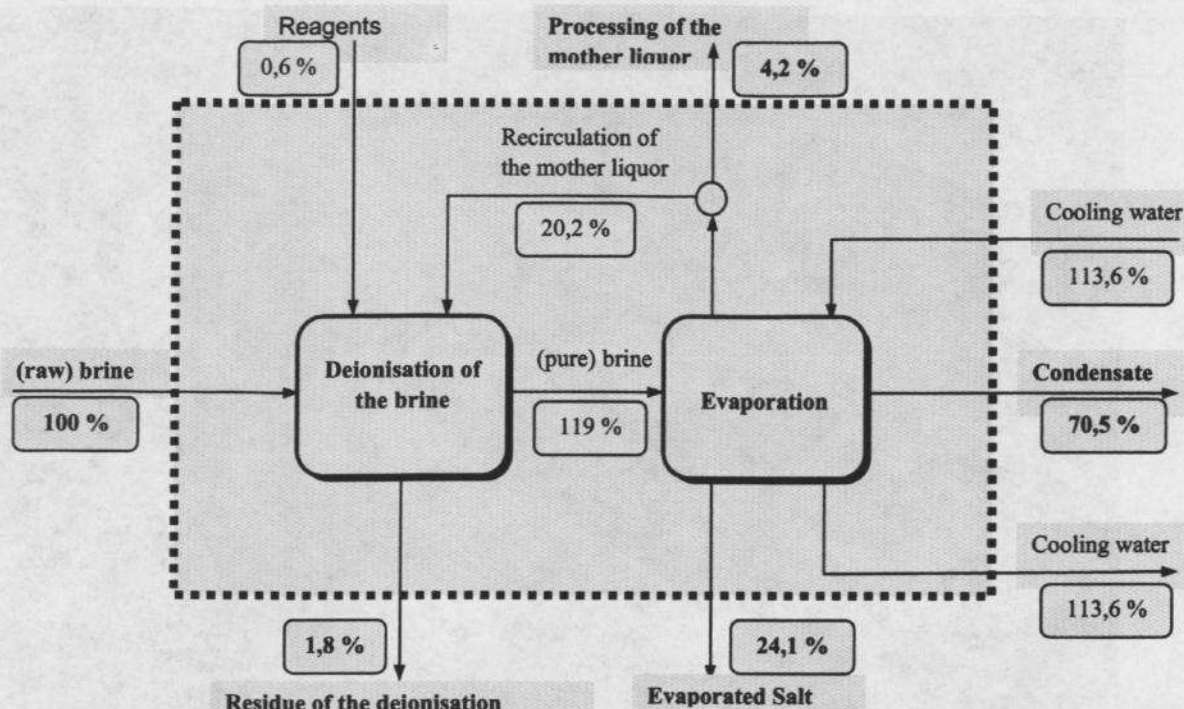


Figure 3: A simplified outline of the process "from brine to evaporated salt"

3 Approaching the problem

Most of the products are produced by the process outlined in chapter 2.2.

Only a very small amount of the range of products is won by drill and blast mining of about head-sized salt pieces. Those are used for the feeding of deer and livestock, as decorative stones or lamps.

The rock salt pieces of up to 300 mm in diameter are evaluated optically and presorted manually. Afterwards, they will be processed by simple processing steps, amongst others by crushing and classifying in lab scale.

The manual pre-sorting is of great importance, as the basic product has to be of perfect quality. This procedure limits the yield and the production capacities.

The aim of the mainly experimentally conducted processing analyses is to evaluate the possibilities and verify the limitations of physical processing techniques instead of the cost-intensive manual pre-separation.

Figure 4 displays a selection of salt products.

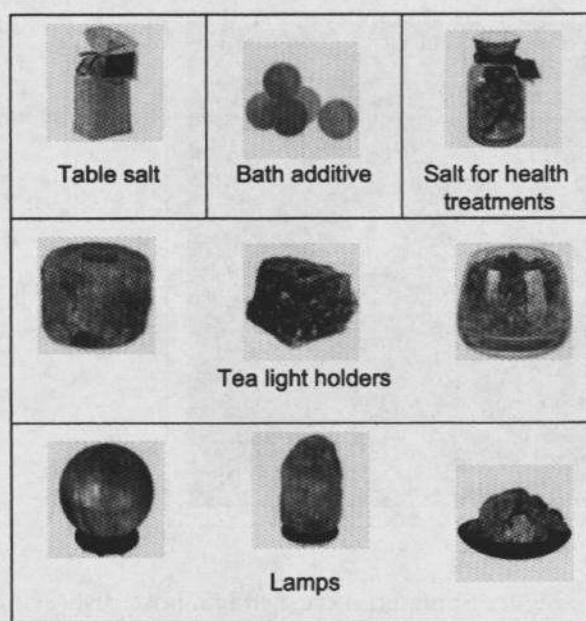


Figure 4: Various products of rock salt produced by the SAAG

4 Quality requirements for natural salts

On the part of the SAAG, the following quality-related parameters were defined:

- Optical uniform appearance, i.e. as free from dark impurities as possible
- Soluble fraction > 97 %
- Suitability as edible
- Flowability
- $k_{\max} < 6 \text{ mm}$

The samples were provided by the SAAG. The fist-sized salt samples were crushed in a jaw crusher to a maximum particle size of 18 mm (see figure 5).

The particle size distribution was determined by manual sieving. The k_{80} -value was 6 mm. About 65 % of the samples exhibited the required particle size of < 3 mm. Only about 2.5 % were smaller than 0.1 mm and therefore negligible. The particle size distribution is displayed in figure 6.

5 Analyses of the raw materials

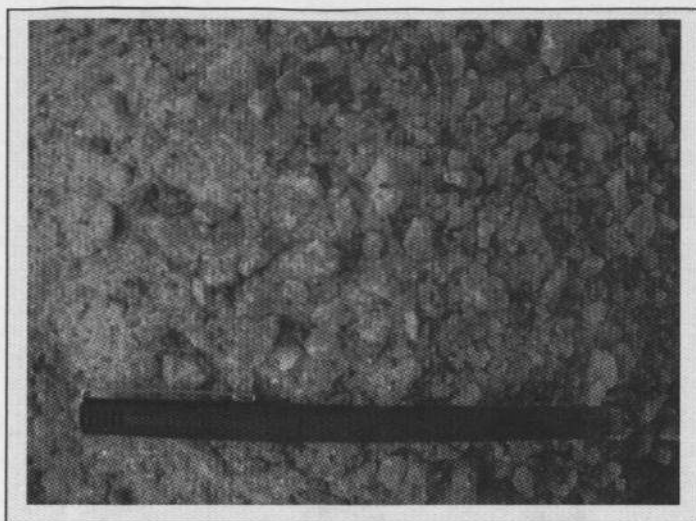


Figure 5: material crushed in a jaw crusher

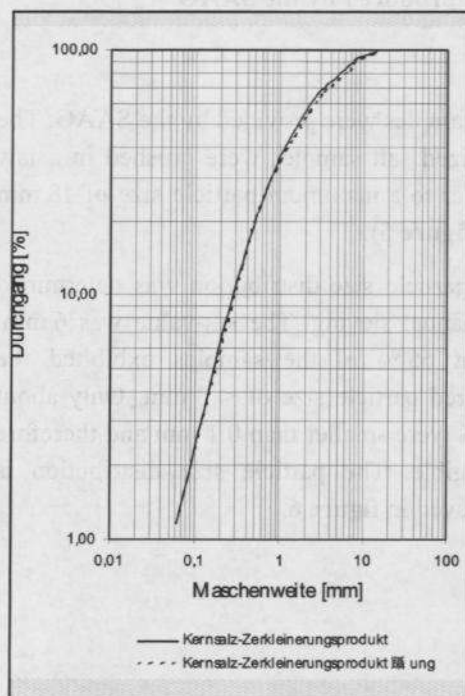


Figure 6: Graph of the particle size distribution

The degree of the intergrowth was analysed with a stereo microscope. The result showed that the mineral phases were liberated satisfactorily in a size range smaller than 1 mm. This information is particularly important for the selection of potential processing techniques.

Not surprisingly, the X-ray-diffraction-analysis reported halite as the major mineral component, with additions of quartz, anhydrite, magnesite, muscovite, illite and chlorite. Moreover, the analysis of the insoluble residues showed traces of iron oxides.

6 Considerations concerning the selection of processing techniques

The use of physical processing techniques requires first differences in the physical characteristics and, second, a satisfactory liberation in particle sizes processable by the chosen technique. As physical processing

techniques (e.g. flotation, density and electrostatic separation) have been used successfully in salt processing for decades, some of the processes should be suitable for the processing of the salt samples in question.

Table 1 specifies the processes in question, analysed processes are bold.

| Separation criterion | Process | Comment | Suitability |
|-----------------------------------|---------------------------------|--|-------------|
| Contrast | Optical separation | Dry, $k_{\min} = 3 \text{ mm}$ | Yes |
| Density | Density separation | Wet, $\Delta \rho = 0.5 \text{ g/cm}^3$ | No |
| Magnetic susceptibility | Magnetic separation | Dry, clay minerals | Yes |
| Electrostatic conductivity | Electrostatic separation | Dry, $k_{\max} = 3 \text{ mm}$ | Yes |
| Wetability | Flotation | Wet, $k_{\max} = 0.25 \text{ mm}$ | No |

Table 1: Listing of possible separation criteria, including processes and comments regarding the suitability

6.1 Processing techniques not further analysed

The use of wet processing techniques is associated with various difficulties – brine management, corrosion, use of reagents, drying of products and treatment of tailings. Therefore, the wet processes were excluded from further analyses.

On the one hand, the wet-operated density separation was excluded from further testing, even though the difference in density between salt and gangue minerals was about 0.5 g/cm^3 and a separation would be possible, as demonstrated in a lab jig.

On the other hand, flotation was eliminated from further testing, because of the use of reagents which rendered the product inedible.

The dry-operated density separation techniques were not analysed either, because of an only very small chance for success. In the meantime, a new, dry operating separator for fine-grained particles has been introduced, called CALA DryFlow Separator from CALA Aufbereitungstechnik GmbH & Co KG. It is possible, that this apparatus may be used for the task in question (but this was not tested here).

6.2 Analysed processing techniques

6.2.1 Optical Separation

The noticeable differences in colour between the salt and the gangue minerals may enable a successful optical separation. The analyses were conducted at the pilot plant of Mogensen

MicroSort. Samples of a particle size between 3.15 and 18 mm were used.

6.2.2 Magnetic separation

Even though all salt minerals are diamagnetic, magnetic separation may be used, because the X-ray-diffraction-analysis proofed the existence of paramagnetic minerals, in particular in the insoluble residues. Therefore the gangue minerals could be separated from the diamagnetic salt minerals by high-intensive-magnetic separation.

6.2.3 Electrostatic separation

Electrostatic separation has been used successfully in the processing of potassium salts since the seventies. This development originates from intense research and development work in Germany. The ESTA-process uses differences in the conductivity of salt minerals in defined environmental conditions, especially humidity.

7 Analyses regarding processing techniques

7.1 Test preparation

Particle sizes of 3.15/2 mm, 2/1 mm, 1/0.5 mm and 0.5/0.1 mm were used to conduct magnetic and electrostatic separation tests at the Institute for Mineral Processing. Particles smaller than 0.1 mm were not analysed because of the negligible mass percentage. In addition to that, this "dust fraction" would result in problems while conducting the test – in particular during electrostatic separation.

The possibilities of measuring the processing success were also considered. In the end, two methods were used: first, the sink-float-analysis at a density of 2.2 g/cm³ and second the solution of the products in distilled water. The data gained was evaluated using balance sheets.

The optimum settings of the apparatus with respect to the particle sizes of the samples were determined by testing (e.g. the roll speed, the position of the splitters, ...). This testing showed that the concentrate can be upgraded further by an after-purification-step.

7.2 Lab instruments used

7.2.1 High-intensity induced-roll magnetic separator „Carpco MIH (13)111-5"

The magnetic force for separating paramagnetic and diamagnetic particles is induced into the iron core by a coil. The iron core induces the magnetic force into the roll, which consists of laminated magnetic- and non-magnetic materials. Therefore, an inhomogeneous magnetic field is generated. The feed material is fed to a stainless steel hopper with a gravity gate mechanism and a vibrating chute, and discharged onto the magnetic roll. Magnetic material stuck to the roll will be wiped off the roll by a brush, whereas non-magnetic material will follow the trajectory. The two material flows are separated by splitters, which allows the generation of middlings.

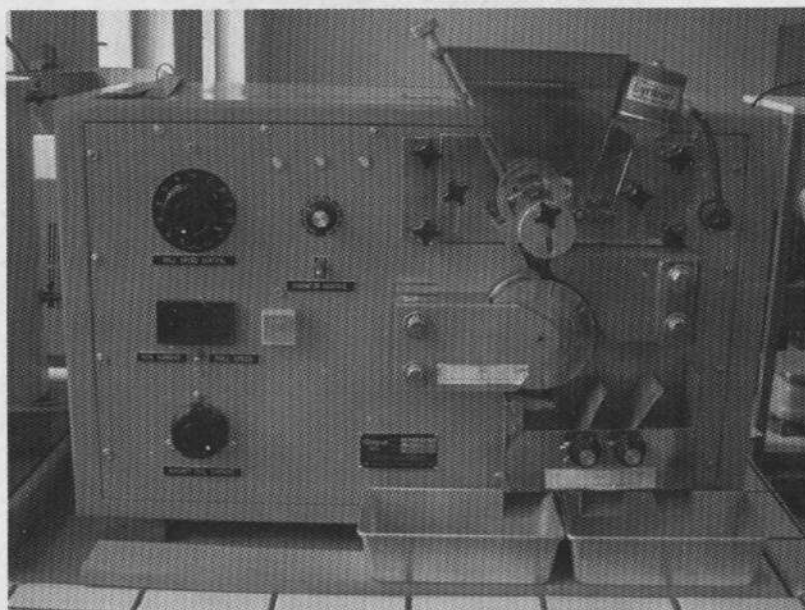


Figure 7: Photograph of the high-intensity induced-roll magnetic separator at the Institute for Mineral Processing

7.2.2 Permanent magnetic high intensity magnetic separator "IFE KP 250-1"

The magnetic force of this separator is generated by a permanent magnetic roll made of rare earths, in this case a neodymium-iron-boron-alloy.

The inhomogeneity of the magnetic field is achieved by a reversing polarity in axial direction. The feed material is fed onto a thin

conveyor belt by a vibrating chute. As before, magnetic material will stick to the conveyor belt running over the magnetic roll and be wiped off when the belt leaves the area of magnetic influence. A brush ensures the removal of all magnetic material from the belt. Non-magnetic particles will follow the trajectory and be separated by a splitter.

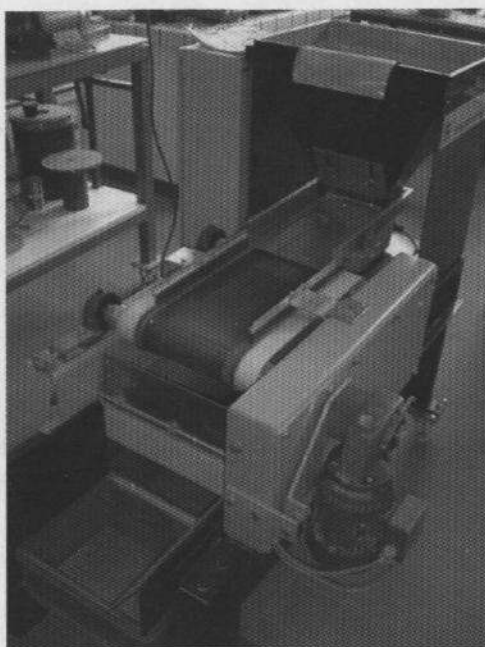


Figure 8: Photograph of the permanent magnetic high intensity separator

7.2.3 Electrostatic roll separator „Carpco HP-167-M“¹³

The analogue generation of high-voltage of this roll separator (figure 7) enables the generation of an electrical potential of up to 50 kV by the use of transformers. The conductive, grounded roll is 150 mm in diameter and powered by a direct current motor and a v-belt power transmission. The

roll speed can be continuously adjusted from 0 to 5 rotations per second, which means a possible operation mode of up to 2.75 times the critical roll speed and a Froude-number of 15. The material is fed by two feed hoppers and a vibrating chute. A multi-stage infrared radiant heater allows separations at higher ambient temperatures.

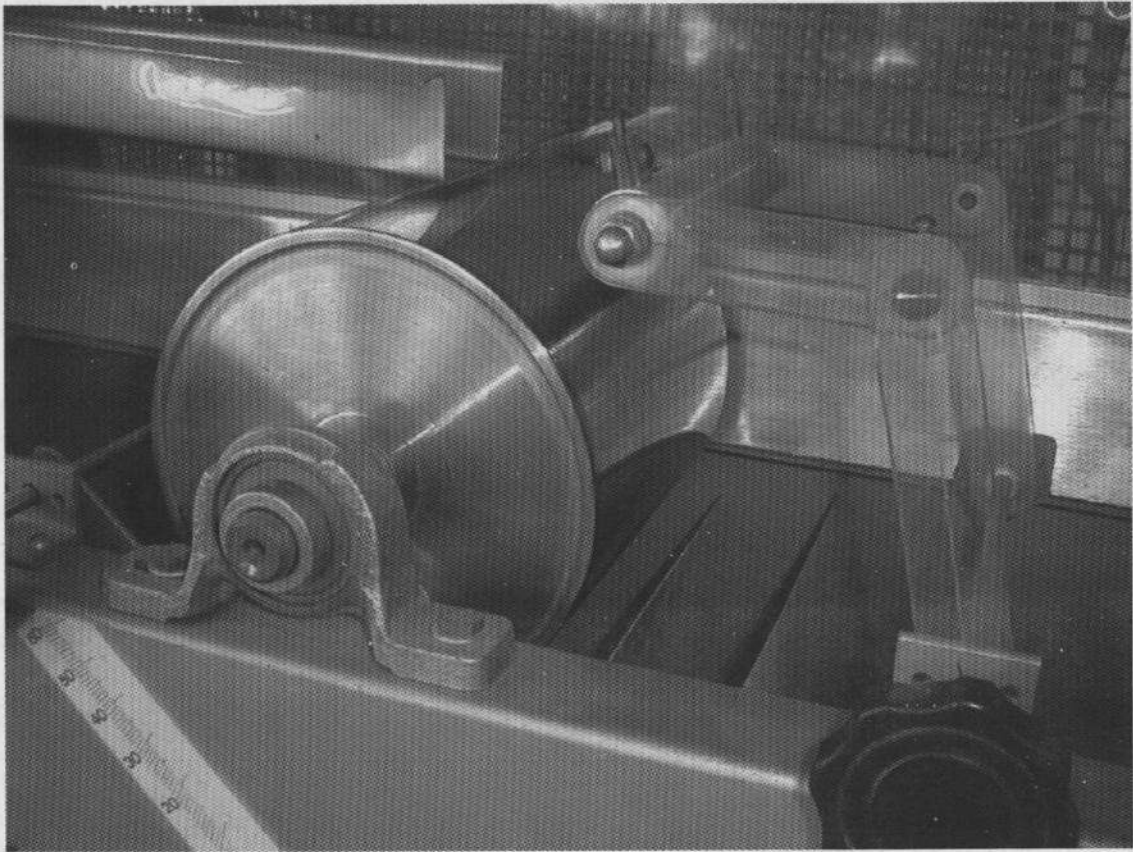


Figure 9: Photograph of the electrostatic roll separator

The system of the electrodes can be used as a roll- or a fine-wired electrode or as a fine-wired electrode with an additional static displacement electrode. Thus the feed material can be analysed for applicable separation techniques by various settings of the lab separator: First, polarization by contact and by ion bombardment (with or without an additional influence by a static displacement electrode) and, second, electro-static and electro-dynamic separation techniques (to separate highly conductive from moderately conductive and conductive from non-conductive minerals).

Two adjustable splitters allow the separation of three products. It is possible to redirect one product back to the feed vibrating chute by a pneumatic pipe conveyor and a corresponding blower.

7.3 Display and interpretation of the test results

7.3.1 Optical separation

The upgrading of the rock salt is possible by this separation technique. As the processable particle sizes have to be bigger than 3 mm and a satisfactory liberation begins at 3 mm, this technique is suitable only for pre-separating the tailings from the concentrate and for pre-upgrading the concentrate.

7.3.1 Magnetic separation

Important results from magnetic separation tests are outlined in **table 2**.

| | Product | Mass yield [%] | Soluble percentage [%] |
|------------|--------------------------------|-------------------|---------------------------|
| 3.15/2 mm | Concentrate after purification | 84.24 | 91.35 |
| 2/1 mm | Concentrate after purification | 86.27 | 93.89 |
| 1/0.5 mm | Concentrate after purification | 88.67 | 97.33 |
| 0.5/0.1 mm | Concentrate after purification | 90.15 | 97.01 |

Table 2: Results from magnetic separation tests

It is demonstrated clearly that the mass yield and the percentage of soluble material improve with decreasing particle sizes. This is attributed to an enhanced liberation. The particle sizes 1/0.5 mm and 0.5/0.1 mm

contain just the required soluble contents of > 97 %.

7.3.2 Electrostatic separation

Important results from electrostatic separation tests are outlined in **table 3**.

| | Product | Mass yield [%] | Soluble percentage [%] |
|------------|--------------------------------|-------------------|---------------------------|
| 3.15/2 mm | Concentrate after purification | 75.97 | 95.95 |
| 2/1 mm | Concentrate after purification | 81.10 | 97.21 |
| 1/0.5 mm | Concentrate after purification | 88.55 | 98.15 |
| 0.5/0.1 mm | Concentrate pre-upgrading | 72.38 | 94.25 |

Table 3: Results from the electrostatic separation tests

In this case as well, the improvement of the mass yield and the content of soluble material could be observed with decreasing particle sizes. Thereby, the particle size 1/0.5 mm contained satisfactorily contents; the size 1/0.5 mm even showed more than 98 % of soluble material. Nevertheless, the achievable percentage decreased clearly at particle sizes of 0.5/0.1 mm.

8 Summary and conclusion

The processing tests demonstrated that the desired product quality of a natural (rock) salt product from alpine deposits could be achieved by the implementation of physical processing techniques.

The most promising solution would be the combination of magnetic and electrostatic separation. Thereby the percentage of soluble material at particle sizes of 2/0.1 mm equalled more than 98 %.

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