Evaluation of Methods for the Process Modeling of Salt Leaching Processes

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ABSTRACT

This paper introduces different methods in order to support the understanding and prognosis of dynamic salt leaching processes in a flooded potash shaft. Here geochemical computations as well as kinetic boundary conditions became part of the regarded data base. The process model has to consider the partly unknown geometrical conditions as well as the complexity of the geochemical processes. The complex intercorrelations of effects in the regarded geosystem make it necessary to include all available information. This requires the discussion of several methods of pre-processing and analysis. This survey will contribute to determine sustainable treatments of possible reclamation in the Stassfurt mining area.

INTRODUCTION

The subject of this paper is embedded in a framework which combines GIS (Geographic Information System) specific characteristics with a non numeric simulation approach. This framework is based on the interdisciplinary project cluster *Development and Application of ICT-based Methods for the Impact Analysis, Prognosis and Control of anthropogenic influenced Processes in Geosystems* supported by the DFG (German Research Foundation).

Figure 1: Location of the investigation area

The investigation area is an old mining shaft within the worldwide oldest potash mining district, near to the city of Stassfurt, Germany (fig. 1).

MINING AREA STASSFURT

The area of Stassfurt had profited from saline mining for hundreds of years. Since 1861 potash was extracted in deep mining systematically whereupon a part of the underground plant was situated underneath the urban area. A part of the cavities area was drowned unintentionally in 1878 to 1922 by fresh water, other parts were still active until 1972. The shaft VI, which is in focus of our investigations, was flooded with brine from 1975 to 1979 (fig. 2). The flooding and leaching process led to a brine filled cavity volume of approx. 20 million m^3. The surface is affected till today by:

- sudden fallen sinkholes,
- a slightly active subsidence,
- a daily drain of approx. 1000 m^3 to avoid a partial flooding of the city by groundwater,
- endangerment from partial highly toxic neglected deposits within the wetting area.

In consequence of the subsidence processes over 850 buildings in the urban area were torn off. The situation for the city of Stassfurt and the region is hardly controllable. The urgency of sustainable geotechnical measures to break the self stimulating cycle of drainage, fresh water inflow and the resulting leaching process is evident (BUSCH ET AL. 2003).

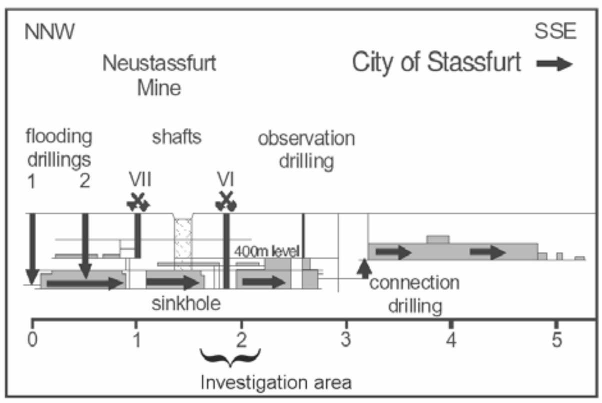

Figure 2: Details of the investigation area

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A special feature in the Stassfurt district was the mining of carnallite, which could be used directly for agriculture purposes. Therefore, numerous excavations exist, whose pillars have a high grade of carnallite, which stimulates the leaching process by high leaching ability. Carnallite is leachable, even by saturated NaCl brine. In order to be able to reconstruct the leaching process accurately, a model under consideration of the mining situation and all mechanical and hydrologic parameters is necessary.

The local mining authority considered several approaches of analytical and numerical calculations (LUX ET AL. 1999). They took into account parameters like chemistry, density, direction of flow, discharge position, water elevation places, convection cells, convergence, as well as natural leaching processes. On the basis of these parameters, hydrological and geochemical monitoring measures were assigned. The results of these measurements refined the model of the leaching process, but still no evaluation was possible, in which way the leaching process will be affected by stopping the drainage. Until now, no plausible prognosis can be given about the behaviour of the induced leaching process (FISCHER UND MAAS 2003).

Motivated by these circumstances we considered to make a new approach of a spatial and time related model of the leaching process, which should be able to provide numerical calculations of stress conditions leading to subsidence prognosis with more reliable boundary conditions. This approach is based on hydrogeochemical computations with stochastic pre-processing strategies combined with a rule based system and a 3 dimensional representation of which certain surface properties can be derived and included in the thermodynamic balances.

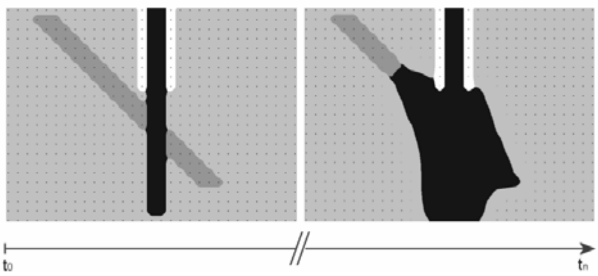

Figure 3: Sketch of the leaching process in a carnallite layer.

THE ENVIRONMENT

This chapter gives a short overview about the environmental settings. This will lead to the necessity of a brief parameter discussion with a main focus on preprocessing strategies.

Geological Settings

The Stassfurt mining district is part of the subhercynian axial depression, which contains the Zechstein formation up to Kainozoic sediments. The saline Zechstein formation consists of six saline cycles (z1 to z6). Within the investigation area the mineable potash beds belong to the Stassfurt cycle (k2/z2). This cycle is developed in layers of carnallite, showing a thickness up to 45 to 55m. Near the axes of the NNW-SSW striking Stassfurt-Oschersleben anticline, the layers dip in an angle of ore than 80° NE. The anticline is covered discordantally ba anhydride and only a few meter of quarternary sediments.

Hydrogeological Settings

Within the flooded underground mine sites and cavities, quantity and quality of the circulating brine is widely unknown. Furthermore a sinkhole, fallen in 1975, caused a hydraulic contact between the underground mining cavities and surface- /groundwater. Therefore, the hydraulic system is an open system and any calculation of soluble and transported compounds is based on assumptions that are difficult to determine.

Hydrogeochemical Settings

Thermodynamic Balances

The solution processes of salinar rocks can be reconstructed by chemical-thermodynamic equilibrium computations (WOLERY 1992) on the assumption of certain boundary conditions. The assumption of a closed system is indispensable regarding the transferred chemical species (masses of soluble) as well as the quantity of the brine (law of continuity). In an open system appropriate boundary conditions have to be estimated and/or replaced by heuristics.

Mechanical Effects

Moreover mechanical aspects affect the underground solution process. Continuous dissolution and re-crystallization cause a changing structure of the salt rock surface. While crystallization processes lead to a partial sealing (masking) of the surface, the sedimentation of insoluble components withdraw parts of the salt rock surface from the solution progress (blocking). In consequence of these processes the proportion of brine volume and salt rock surface varies and therefore crucially influences the development of the entire solution process.

Kinetic Effects

Kinetic parameters (as well as mechanical) are so far barely considered in available geochemical computer models or they are only integrated indirectly. Kinetic parameters could be derived from the pitch of the contact surface between the solid and the liquid phases. This angle affects local convection cells. These cells should be determined as solution cells, which act homogeneous in the chemical-thermodynamic equilibrium computations. Knowing these cells it becomes also possible to assign a certain expanse of the contact area that is necessary in a balance computation.

NECESSITY FOR NEW APPOACHES

The necessity for sustainable geotechnical measures in the Stassfurt district is obvious. The expected ground movements and sinkholes as well as the associated flooded areas do not only threaten buildings and infrastructure. The numerous dump locations in the potential flooded areas endanger also the health of the inhabitants. The determination on a remediation concept is difficult, because of the lack of knowledge and the complexity of the in situ mine damage. Conventional approaches for the modeling of the causative leaching process fail due to fuzzy parameters and undetermined boundary conditions. The main dependencies, that are not included in common geochemical computer models, are the reciprocations between metric, topologic and thematic issues. With the interdisciplinary research project described above, the feasibility of new approaches is evaluated. This takes place first for a limited investigation area. The methodical approach could be subsequently extended to wider areas of the excavation.

SUGGESTED MODELLING TECHNIQUES

In general the salt leaching process can be reconstructed by chemical-thermodynamic equilibrium computations. Those models provide mass and volume balances between the fluid (brine) and the solid (rock) phases with a certain compound.
The salt deposit in the investigation area has a layered structure (fig. 4) where alternating more or less potassium bearing salt appears. Since salt rocks of different composition shows different leaching characteristics, they necessarily have to be distinguished in a corresponding process model. Especially layers with a high grade of carnallite, which stimulates the leaching process by high leaching ability, could not be described as a homogeneous area while that layer itself has varying attributes that influences the leaching process (MAAS 2001).

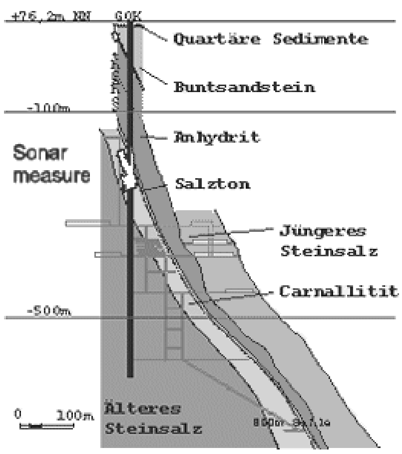

Figure 4: Profile of the salt deposit in the investigation area

Pre-processing

Those mentioned attributes that affects the leaching process can be characterize as

- amount of insoluble components
- fraction of chemically combined water
- porosity, permeability
- rock temperature, brine temperature
- rock stress
- viscosity of salt

Chemical components of the carnallit layer are known from detailed lithological profiles, that can be assigned to the investigation area (fig. 6).
Data pre-processing should lead to spatial clusters that act homogeneous in chemical-thermodynamic equilibrium computations. Different techniques of cluster analysis are well known as a fundamental operating principle in statistics. Thereby it is imperative that the given dataset suites to certain pre-requisites.

A neural based cluster analysis can be performed by unsupervised network topologies such as self organizing feature maps (SOM). The main advantage of this method is that in case of non-linear relations between parameters no standards of equation systems must be assumed or determined by iterative loops. Furthermore no limitations in reference to the amount of given samples or their distribution must be considered. The basic algorithm follows certain learn and optimization strategies that approximate separation functions autonomously. The result of a neural based cluster analysis by SOM can be represented as patterns of activity on a 2 dimensional maps of interconnected neurons (fig. 5). Correlating parameter will show a similar activity, whose significance must be determined by experts knowledge (KOHONEN 1997).

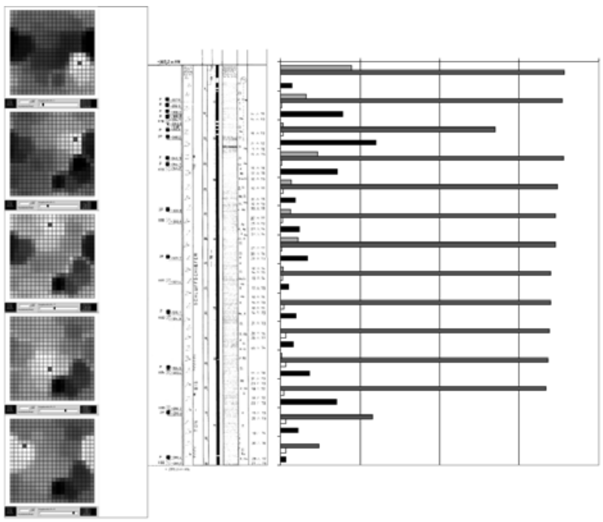

Figure 5: SOFM based cluster analysis of borehole sections (ZEMKE 2003)

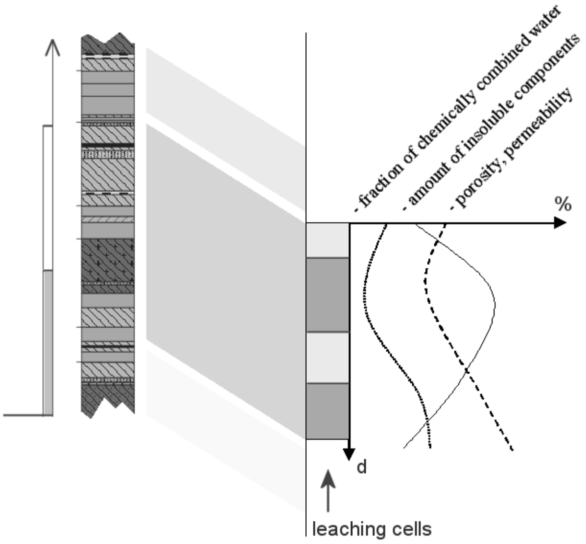

Figure 6: Pre- processing of data, detection of leaching cells (schematic sketch)

Rule Based Systems

Assuming that we have determined the leaching cells by cluster analysis, we can compute the mass-volume exchange between fluids and solids by chemical-thermodynamic equilibrium balances. But still no kinetic or mechanic influences are involved in the leaching simulation. Our approach tries to combine a rule based systems with geochemical computer models in a GIS architecture.

Fuzzy Based Approach
The first association that occurs when you think of rule based systems is a fuzzy based approach. Fuzzy systems provide simple strategies to rule complex data structures by linguistic statements (MÖLLER 2003). The regulator consists of a specification of the situation (IF – part) and its resulting reaction (THEN – part). The IF – part is composed by one or more conditions, which are combined logical by operators (AND / OR). The evaluation of the definition of the situation is realised by an inference operator that checks for the degree of performance of the defined fuzzy rules. Finally combining operators lead to conclusions about the system behaviour by evaluating the respective conditions (fig. 6).
The specific Impact analysis is defined by an adequate appending or deleting of rules. To support this complex incident, the content of truth of each rule can be modified by an association factor. This value associates a factor to each rule, which can be used as an individual weighting for certain criteria. It can also be used for the adjustment of rules while calibrating the process model. Several possibilities exist to link self learning algorithm to this manipulating factor (GRIMA 2000).

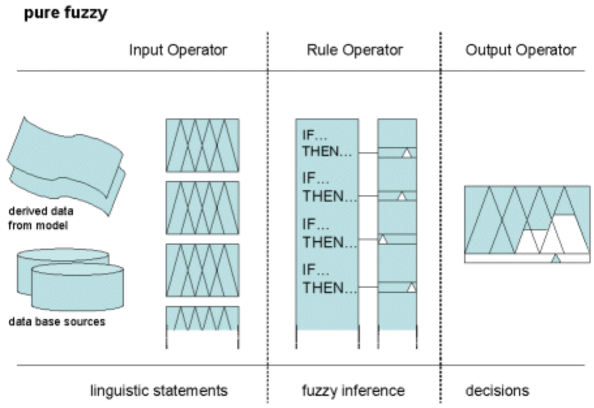

Figure 7: Simplified structure of the fuzzy rule based system.

Alternative Approaches
As an alternative to a fuzzy based rule system our current research is evaluating neural network based algorithms. *Causal Networks* or their increments *Bayes Networks* describe miscellaneous applicable structures for the compact processing of complex data. They are often used in context of expert systems (JENSEN 1996).
Finally neural networks with a supervised learning algorithm such as *Backpropagation* (*BPN) Networks* could be adopted, if the impact structure of a system is generally known (fig. 8). Those algorithm have been successfully tested in other environments (ZEMKE ET AL. 2003).

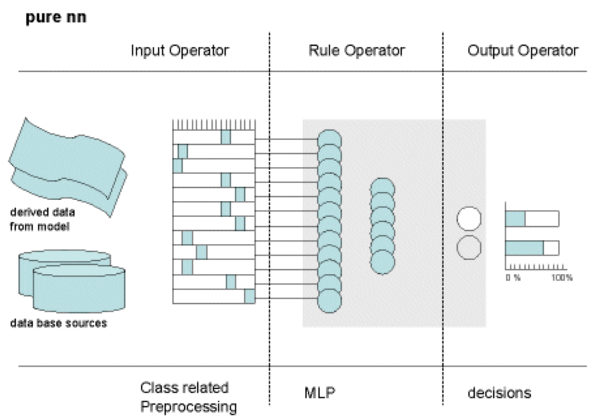

Figure 8: Simplified structure of the BPN rule based system.

EXPECTED RESULTS

This paper can not reach a conclusion while the mentioned research topics aren't sufficiently compiled yet. But the combination of the suggested ICT methods should lead to results, that help to detect sustainable geotechnical measures in the Stassfurt district.

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