Backfilling and Sealing Materials

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Introduction

The concept of the long-term safe disposal of wastes in underground disposal facilities is based on several independent barriers:

- immobilized waste,
- engineered barriers,
- natural rock
- further natural formations above.

By preventing or minimizing the contact between water and waste, the multi barrier system provides an isolation of the waste from the biosphere.

The engineered barriers must be chemically and physically compatible with the host rock and the waste.

That implies different and specific materials for each geological host rock.
Engineered Barriers (EBS) in underground repositories /BRA 08/
Functions of the backfilling and sealing materials

1. Guaranteeing compliance with the protection goal
2. Technical functions connected with the mining activities
3. Specific functions connected with particular aspects of the disposal facility
1. Compliance with the protection goal

According to German regulations for the underground disposal of hazardous chemical wastes, compliance with the protective goal is linked mainly to the stabilization of the mine workings.

The emplacement of backfill enhances the total stability of the surrounding host rock. The concentration of differential stresses and failure of the host rock can thus be avoided.

Backfill and sealing materials are used for the construction of technical seals with well-defined hydraulic, mechanical, and chemical properties.

These materials reduce the extend of the excavation damaged zone (EDZ) in the mine workings and prevent subsidence damages on the surface.
2. Technical functions connected with the mining activities

- Increasing the amount of extractable ore
- Avoiding additional waste rock piles above ground
- Avoiding roof falls
- Reducing maintenance costs

3. functions connected with particular aspects of the disposal facility

- Backfill is an integral part of the multi barrier concept
- Backfill largely reduces the open pore space which can be filled with water or brines. The water path is the main vehicle for the mobilisation and transport of toxic substances.
Types of backfill and their functions in an underground disposal mine /BRA 91/
Crushed Salt

Crushed salt is the most important backfill material in salt mines. It is a coarsely grained material with a maximum grain size of 60 mm produced during the excavation process in salt mines.

The initial porosity of pneumatically emplaced crushed salt backfill is about 35%.

Due to the creep of the surrounding salt the initial permeability of the crushed salt backfill will be reduced continuously until it finally reaches the extremely low permeability of about $10^{-21}$ m$^2$.

Complete encapsulation and isolation of the waste containers will eventually be reached.

From a mineralogical and geochemical perspective, crushed salt is an ideal barrier material in salt formations as it is in thermo dynamical equilibrium with the host formation and all potentially occurring brines.

The thermo mechanical and geochemical behaviour is well understood and can be predicted with accuracy /ROT 04/ /HER 10/.
Pneumatic emplacement of crushed salt in the Asse mine (Pictures: Asse GmbH)
Self-Sealing Backfill (SVV)

Another salt based backfill material, the self sealing backfill SVV is able to prevent water intrusion to the wastes immediately after emplacement.
Self-Sealing Backfill (SVV)

The addition of anhydrous MgSO$_4$ to crushed salt can render the backfill into a reactive salt mixture that upon contact with brine increases its volume and leads to the formation of a very effective seal. This special salt backfill material is called SVV (= self-sealing salt backfill).

Solid phases:
- original Halite
- original MgSO$_4$
- hydrated MgSO$_4$
- new minerals

Pore space:
- Gas phase: air
- Fluid phase: brine

Brine contact:
Metamorphism of solid phases; new solids consume fluids

Sealing:
new solid phase; filled pores; impermeable

Principle of the self-sealing salt backfill SVV /SAN 00/
SVV - Pictures /HER 10/
The geochemical modelling allows the quantification of the short- and long-term volume changes in the system and confirms that in the long run stable mineral assemblages will be obtained.

The mechanical properties are comparable with those of undisturbed rock salt.

These results show that SVV is a self-sealing, long-term stable and predictable sealing material.

Self-sealing backfill (SVV)
Volume changes due to the reaction with brines
Laboratory and In-situ experiments with SVV

Pictures: /HER 10/
Technical aspects of SVV emplacement /HER 10/
Cement based Materials

Concretes are part of EBS concepts in all kinds of host rocks. Concretes are also used for the conditioning and solidification of liquid and other waste forms. These materials have the potential for chemical and physical retention of toxic substance. In general they are tolerant against many solutions and materials in contact with high saline solutions cementitious materials can be corroded. Corrosion changes their structure, their mechanical and hydraulic properties, and thus their sealing potential. The safety assessment for a repository system implies detailed knowledge of the geochemical behaviour of cements and concretes in their environment. The reactions with aqueous solution result in changes of the solution’s composition and pH. These changes have an impact on the long-term performance of the technical barriers and on the solubility of the toxic substances in the repository.
Cement Based Materials - Saltcrete

Saltcretes are mixtures of Portland cement and additives (crushed rock salt and fly ash) and water.
The recipe used in the repository Morsleben, the so called M2, consists of 328 kg CEM III-cement, 1072 kg crushed salt, 328 kg fly ash, and 267 kg water.

Saltcrete has two specific properties:
1) saltcrete shrinks due to evaporation of water, and
2) saltcrete creeps like rock salt under a constant load.

The mineral phases which are responsible for the stability are CSH and CAH minerals.

CSH and CAH are stable in the presence of Na and Ca rich brines but unstable in Mg rich brines.
Cement Based Materials - Saltcrete

The reactions of saltcrete with brines are well known and can be modelled. The long-term behaviour is reliably predictable.
Cement Based Materials - MgO Concrete

MgO concretes are stable and can therefore be used in chemical environments where saltcretes are not stable.
MgO concretes are long-term stable in potash mines with MgCl₂ rich brines. MgO concretes or Sorel concretes contain Mg-Si-hydrates, which are formed in the reaction of MgO and MgCl₂.

The main phases responsible for the stability are:
- 3-1-8 phase (Magnesiumoxidchlorid: Koshunowskit) a thermo dynamically long-term stable mineral in brines with MgCl₂ contents above 50 g/l.
- 5-1-8 phase, a metastable mineral
- 9-1-4 phase, a high temperature phase

The thermo dynamic properties of the MSH phases are well known for ambient temperatures.
They must still be determined for higher temperatures.
MgO concretes can reach very high hardness and they cure very fast.
The highest degrees of hardness can be reached with the 5-1-8 phase.
The 5-1-8 phase, however, is metastable and will be converted in the thermo dynamically stable 3-1-8 phase.
The mechanical consequences of this transformation still have to be investigated.
MgO Concrete - continued

Depending on the recipe and the temperature, MgO concretes may shrink, maintain their volume or expand. The technological handling of this type of concrete is not easy but it can be handled. Presently dams of MgO concrete are built in the Asse salt mine.

A typical recipe is:

- Cement: MgO cement, 0.220 t/ m³
- Additive: crushed rock salt, 1.234 t/ m³
- Mixing fluid: MgCl₂ (Q-)brine 0.485 t/ m³
Large-scale industrial equipment for mixing and pneumatic emplacement of MgO concrete in the Asse mine (Pictures: Wallmüller, Asse GmbH)
Emplacement of MgO concrete in the Asse mine
Pictures Asse GmbH
Emplacement of MgO concrete in the Asse mine
Pictures Asse GmbH
Other Backfill and Sealing Materials - Bentonites

Bentonites are important EBS materials for repositories in all kinds of host rocks, including salt, clay, and crystalline rocks.

Compacted bentonites will be used for the construction of shaft, drift, and borehole seals.

Bentonites are considered to be ideal sealing and backfilling materials because of their swelling capacity.

The swelling develops when bentonites react with water or aqueous solutions. The swelling capacity is the key parameter of all technical barriers build with compacted bentonites.

Due to the swelling the pore space of the compacted bentonite is reduced and water flow is inhibited. Thus the mobilisation and transport of toxic substances can be reduced considerably.
Bentonites - continued

A drift sealing system combining bentonite-sand bricks and compacted crushed salt bricks was tested in the potash mine in Sondershausen.

A shaft seal combining crushed salt and bentonite has recently been tested at the Salzdetfurth mine.

Nevertheless reliable conceptual models which can predict the combined hydro-mechanical behaviour of seals with compacted bentonites are not yet available.

The kinetics of the reaction that reduces the swelling capacity in contact with different solutions in not yet known.
Combined materials

Mixtures of:
- Crushed salt + bentonite
- Crushed salt + anhydrous MgSO4
- Bentonite + sand
- Conretes + bitumen/asphalt

Triaxial: T = 70 °C, \( \sigma_m \leq 14.2 \text{ MPa} \)
\( \text{t} = 70 \text{ d} \)
\( \rightarrow e \approx 0.02 \)

Combination of crushed salt and bentonite /STU 10/
Conclusion

A large variety of different backfill and sealing materials with well-known properties are available.

The optimal combination of these materials guarantees very effective EBS systems and the long-term safety of underground disposal facilities in all kinds of host rocks.
Thank you for your attention