Coupled Modelling of Convergence, Steel Corrosion, Gas Production and Brine Flow in a Rock Salt Repository

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> Motivation

Anaerobic iron corrosion causes considerable volume increase of solid material, resulting in

- Stress to the host rock, reducing convergence
- Reduction of volume for storage of brine and/or gas
- Release of contaminated brine

◊ Corrosion is probably essential for pressure and flow

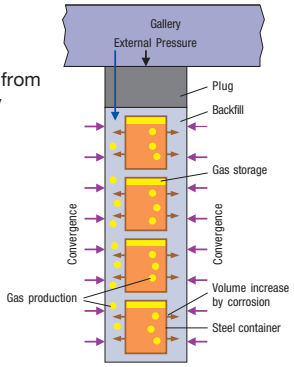
Mechanical influence of corrosion has not yet been taken account of in the Integrated PA code LOPOS

> Effects to be considered

- Convergence by creeping of rock salt
- Backfill and waste compaction
- Porosity-dependent flow resistance
- Anaerobic corrosion
  - Iron-to-magnetite transformation
  - Gas production
  - Brine consumption
  - Water consumption and salt precipitation
- Pressure development

> Release from a borehole

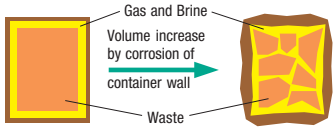
- Brine intrusion into the borehole from brine pockets or from the gallery
- Presence of a driving force:
  - Convergence
    - ◊ Reduction of available void volumes
  - Gas production
    - ◊ Displacement of liquid from gas storage volumes
  - Steel corrosion
    - ◊ Volume increase of solid material



> Corrosion of a thick-walled steel container

Decrease of void volume in a waste container by:

- Convergence
- Corrosion
- Salt precipitation



> Modelling

- Anaerobic corrosion

$$3\ Fe + 4\ H_2O \longrightarrow Fe_3O_4 + 4\ H_2$$

Volume of 3 moles of Fe [cm³]	21.21
Volume of 1 mole of Fe_3O_4 [cm³]	44.52
Volume increase factor	**2.0996**

- Precipitation of salt

NaCl content of saturated brine [g/mol H_2O]	6.54
Density of saturated NaCl-brine [kg/m³]	1193
Density of solid NaCl [kg/m³]	2168
Volume ratio: salt precipitate/consumed brine	**0.1466**

- Time development of pore volume

$$V_P(t) = \phi_S(t) \cdot V_S(t) + \phi_W(t) \cdot V_W(t) - \left(V_{So}(t) - V_{So}(0)\right)$$

- Convergence of total borehole volume:

$$\frac{dV_{PS}}{dt} = -K \cdot V_S$$

- Gas volume
  - gas production
  - gas release
  - pressure change

$$\frac{dV_G}{dt} = \left(\frac{\dot{n}_G}{n_G} - \frac{\dot{p}_G}{p_G}\right) \cdot V_G$$

- Solid volume
  - iron corrosion
  - salt precipitation

$$\frac{dV_{So}}{dt} = \Omega_{So} \cdot \dot{n}_G$$

- Brine Volume
  - in-/outflow
  - water consumption

$$\frac{dV_B}{dt} = S - \frac{dV_{B\rightarrow G}}{dt}$$

Variables

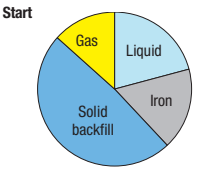
V = volume
ϕ = porosity
p = pressure
n = molar amount
S = net flow

Indices

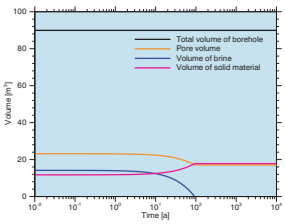
P = pores
S = backfill
W = waste
So = iron + magnetite + precipitate
G = gas
B = brine

> Test examples

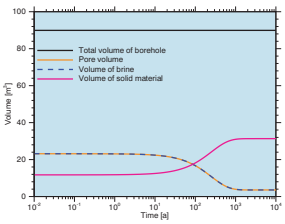
Test examples	1	2	3
Brine-filled pore volume	yes	yes	yes
Replenishment of brine	no	yes	yes
Gas storage	no	no	yes
Convergence	no	no	yes



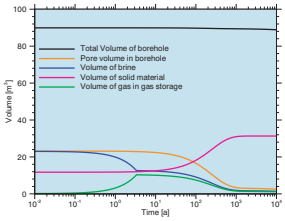
Volume balance estimation for test example 1



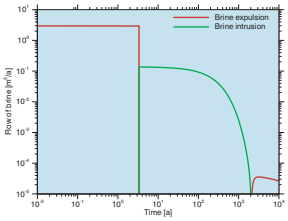
Example 1: Time development of volumes



Example 2: Time development of volumes



Example 3: Time development of volumes



Example 3: Time development of flows

> Résumé

- Test example 1 shows that the numerical model yields the expected results
- Test example 2 shows the relevance of volume increase of solid material
- Test example 3 shows the relevance of gas storage

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