Dynamical Models for Uranium Leaching

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More Info:

H. Kalka, H. Märten, R. Kahnt: Dynamical Models for Uranium Leaching – Production and Remediation Cases

Dynamical Models for Uranium Leaching - Production and Remediation Cases -
Dynamical Models for Uranium Leaching

1. Model Concept
2. Production Case
   In-situ Leach at Beverley Mine
3. Remediation Case
   Flooding of Königstein Mine
Dynamical Compartment Models

- Local conditions
- Available data
- Spatial-time structure
- High time resolution $\Delta t \geq 1$ h
- Mass and charge conservation
- Modular design with C++

Transport
Kinetics
Thermodynamics

PHREEQC
Basic Equations (site-specific)

\[
\frac{dm_i}{dt} = \left( \frac{dm_i}{dt} \right)_{adv} + \left( \frac{dm_i}{dt} \right)_{nat} + \left( \frac{dm_i}{dt} \right)_{techn}
\]

- **natural processes**
- **technological processes**

**advection**

\[
\left( \frac{dm_i}{dt} \right)_{adv} = \sum_{j=1}^{N} \left[ Q_{j\rightarrow i} c_j - Q_{i\rightarrow j} c_i \right] + Q_{i in} c_{in} - Q_{i out} c_i
\]

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ISL Beverley Mine

Australia’s first commercial acid ISL mine since 2000
Wellfield / Wellhouse

complex flow pattern
averaging over ore grades, hydraulic parameters

- injection -

- extraction -
First: Analytical Approach

\[
\frac{dm^{\text{ore}}}{dt} = -\lambda m^{\text{ore}}
\]

\[
m^{\text{ore}}(0) = m_0 = c_0 V_p
\]

\[
\frac{dm}{dt} = \lambda m^{\text{ore}} - qm
\]

\[
m(0) = 0
\]

\[
c(t) = c_0 \frac{\lambda}{\lambda - q} \left\{ e^{-qt} - e^{-\lambda t} \right\}
\]
Three Parameters

\[ c_0 = \frac{m_0}{V_p} \]

initial concentration

\[ c(t) = c_0 \frac{\lambda}{\lambda - q} \left\{ e^{-qt} - e^{-\lambda t} \right\} \]

\[ \lambda = a \cdot e^{b(2-pH)} \]
dissolution rate

\[ q = \frac{Q}{V_p} \]
flushing rate

Example

\[ m_0 = 200 \text{ t } U_3O_8 \]
\[ V_p = 30 \text{ 000 m}^3 \]
\[ Q = 200 \text{ m}^3 / \text{h} \]

USiO₄

\[ a = 0.5 \cdot 10^{-7} \text{ s}^{-1} \]
\[ b = 3.2 \]
Uranium in the Lixiviant

\[ c_0 = 5.7 \, \text{g/L} \]
\[ q = 0.160 \, \text{d}^{-1} \]
\[ \lambda = 0.016 \, \text{d}^{-1} \]

\[ c_0 = 6.4 \, \text{g/L} \]
\[ q = 0.136 \, \text{d}^{-1} \]
\[ \lambda = 0.011 \, \text{d}^{-1} \]

SO\(_4\), Cl, Fe, Ca, Si ?

geochemical model

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Beverley Mine

ISL Production Circuit
ISL Cycle

Compartement Structure

Dosage

Orebody

WH 1
WH 2
WH 3
WH 4
WH n

individual dosage

dissolution of primary minerals (irreversible)

equilibrium with secondary minerals (reversible)

groundwater

diss. precip.
ISL - Numerical Model

- leaching + IX
- time behavior of pH, ORP
- U, SO₄, Cl, Fe, Ca
- Na, Al, Mg, K, Si
- interfering leaching
- silicate minerals
- ... and material balance in the cycle

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**IX columns (Uranium Recovery)**

**Sorption**
- pregnant Lix

**Elution**
- eluant (NaCl)

- Bed Volume
  - Head
  - Tail

- Resin Loading
  - RHSO4
  - R(SO4)0.5
  - RCl
  - R(UO2)0.5SO4

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Königstein Uranium Mine

South-East Saxony (near Dresden)

1967 mining
1984 acid ISL

1991 decommissioning
2001 start flooding

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Internal Structure of a Compartment

- Compartm. 1: Mobile water mass transport
- Compartm. 2: Stagnant water mass production & storage
Mass Transfer (Leaching)

\[
\frac{dm_i^F}{dt} = \left( \frac{dm_i}{dt} \right)_{\text{trans}} + Q_i^{\text{exch}} (c_i^p - c_i^F) + m_i^{\text{sekm}} \delta (t - t_i)
\]

\[
\frac{dm_i^p}{dt} = -Q_i^{\text{exch}} (c_i^p - c_i^F)
\]

**long-term source**

**short-term source**

**density driven:**

\[
Q_i^{\text{exch}} = \Lambda \left( \rho_i^p - \rho_i^F \right) / \rho_0
\]
The Software “Flooding II”

- hydraulics
- geochemistry

1 hour on PC

2 year forecast

1 000 000 × PhreeqC
Step-by-Step Approach

First Flooding Experiment
Second Flooding Experiment

Model Calibration

1993 1997 2001

Fine Tuning

2005

Forecast

Sulfate [mg/L]

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Königstein Mine - Forecast

Time dependence

- pH
- 15 elements
- hydraulics
Conclusions

The Models were used to

- Evaluate dynamics of mine/process water chemistry
- Select optimized strategies for leaching/remediation
- Interpret laboratory and pilot experiments
- Systemize chemical and hydraulic field data
- Derive a guidance for process monitoring