Solubility and TRLFS study of Nd(III) and Cm(III) in dilute to concentrated $NaCl–NaNO_3$ and $MgCl_2–Mg(NO_3)_2$ solutions

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Introduction

- Long–term performance assessment of deep geological nuclear waste repositories → prediction of chemical behavior of An and long lived FP in aqueous solutions needed.
- Waste disposal in rock–salt formations in USA; option under consideration in Germany → high $[Na^+]$, $[Mg^{2+}]$ and $[Cl^-]$ expected in water intrusion scenarios.
- Nitrate can be found in high concentrations (≥ 1 M) as part of certain waste forms → waste originated from reprocessing facilities.
- Previous complexation studies with nitrate focused on acidic conditions; no $MgCl_2$ systems considered.

Objectives of this work

- **Assessment of NO_3^- effect on Ln(III)/An(III) solubility under repository relevant conditions.**
- **Development of chemical, thermodynamic and activity models for the system Ln(III)/An(III) in $NaCl–NaNO_3$ and $MgCl_2–Mg(NO_3)_2$ solutions.**

Experimental

Solubility experiments

- Batch experiments in Ar atmosphere (22 ± 2°C)
- Undersaturation approach in 0.1–5.0 M $NaCl–NaNO_3$ and 0.25–4.5 M $MgCl_2–Mg(NO_3)_2$ mixtures → **up to 7 M NO_3^-**
- pH range: $7.5 \le pH_m \le 13.0$

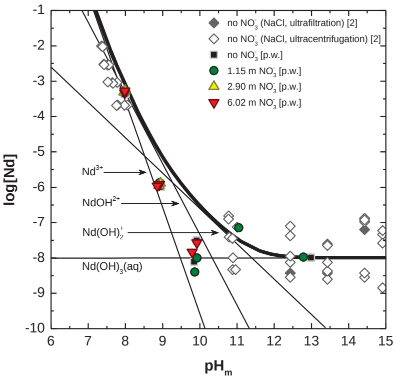
- 6–12 mg $Nd(OH)_3$(am) solid phase used in each experiment
- Equilibration time: t ≤ 500 days
- pH measurements: $pH_m = -\log m_{H^+} = pH_{exp} + A_m$ [1]; A_m for $Cl^-–NO_3^-$ mixtures determined in this study
- [Nd(III)] measured by ICP–MS after 10 kD (2-3 nm) ultrafiltration
- Solid phase characterization: XRD, SEM–EDX

Cm(III)–TRLFS

- Sample preparation in Ar atmosphere (22 ± 2°C)
- TRLFS studies in 5.0 M $NaCl–NaNO_3$, 0.25 and 3.5 M $MgCl_2–Mg(NO_3)_2$ mixtures → **up to 7 M NO_3^-**
- pH range: $1 \le pH_m \le 9$
- [Cm(III)] ~1×10^{-7} M per sample

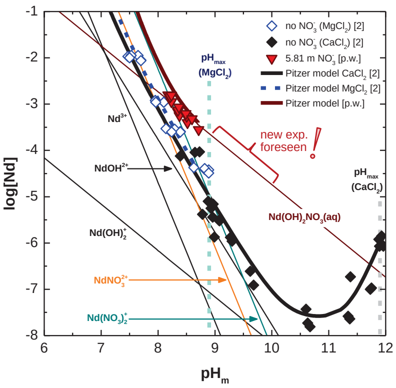
Results and discussion

Solubility of Nd(III) in 5.0 M $NaCl–NaNO_3$



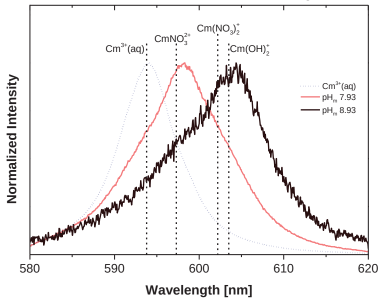
- Very good agreement with nitrate–free solubility data reported in [2].
- No effect of NO_3^- on $Nd(OH)_3$(am) solubility in $NaCl–NaNO_3$ systems **(even in 5 M $NaNO_3$)**.

Solubility of Nd(III) in 3.5 M $MgCl_2–Mg(NO_3)_2$



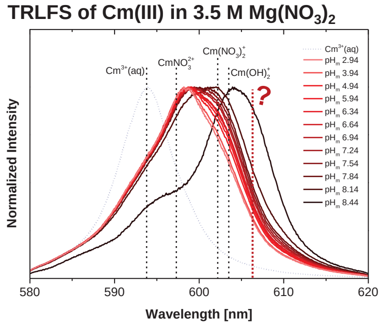
- Significant effect of $[NO_3^-]$ on $Nd(OH)_3$(am) solubility.
- Slope of solubility curve increases at $pH_m \ge 8.44$ → change in number of OH^- involved in solubility reaction.
- Additional experiments in $CaCl_2–Ca(NO_3)_2$ (pH_{max} ~12) planned to confirm this trend.
- *Handouts with experimental data at other ionic strength can be shown upon request.*

TRLFS of Cm(III) in 5.0 M $NaNO_3$



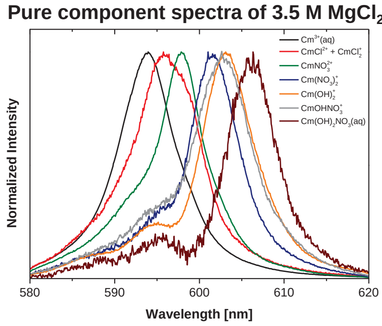
- $CmNO_3^{2+}$ prevails in 5 M $NaNO_3$ and $pH_m < 8.93$.
- $Cm(OH)_2^+$ dominates at $pH_m \ge 8.93$.
- No clear evidence of relevant ternary Cm–OH–NO_3 species in 5 M $NaNO_3$.

TRLFS of Cm(III) in 3.5 M $Mg(NO_3)_2$



- $CmNO_3^{2+}$ and $Cm(NO_3)_2^+$ forming at $pH_m \le 8.14$, in good agreement with thermodynamic calculations based upon [3].
- New (ternary) species arising at $pH_m \ge 8.44$.
- Three ligands complexing Cm(III) based upon red shift: 1 Cm(III) : 2 OH^- : 1 NO_3^-.

Pure component spectra of 3.5 M $MgCl_2–Mg(NO_3)_2$



- Nitrate effect → genuine complexation reaction!
- Very complex Cm(III) speciation found in $MgCl_2–Mg(NO_3)_2$ mixtures → two ternary Cm–OH–NO_3 species forming.

Chemical and thermodynamic model for the system $Nd^{3+}/Cm^{3+}–H^+–Mg^{2+}–OH^-–Cl^-–NO_3^-$

(preliminary Pitzer model available upon request)

- Solid phase controlling solubility: $Nd(OH)_3$(am) (XRD, SEM–EDX).
- Slope −1 in presence of NO_3^- and $pH_m \ge 8.44$ → 1 Nd(III) : 2 OH^- (solubility).
- Binary Cm(III)–NO_3 species relevant for $pH_m \le 8.14$ (TRLFS).
- Formation of $Cm(OH)_2NO_3$(aq) indicated by TRLFS at $pH_m \ge 8.44$.

$$Nd(OH)_3(am) + H^+ + NO_3^- \Leftrightarrow Nd(OH)_2NO_3(aq) + H_2O$$

Conclusion and outlook

- **Nitrate significantly influences solubility of $Nd(OH)_3$(am) in concentrated and weakly alkaline $MgCl_2–Mg(NO_3)_2$ solutions at $[Mg^{2+}] \ge 2.5$ M and $[NO_3^-] \ge 1$ M.**
- **TRLFS data confirm that the effect of NO_3^- on solubility is resulting from complex formation reactions and not related to matrix effects (presence of NO_3^- instead of Cl^-).**
- **A chemical model has been proposed including the formation of the ternary aqueous species $Nd(OH)_2NO_3$(aq) in equilibrium with solid $Nd(OH)_3$(am).**
- **Thermodynamic and activity models (Pitzer) for $Nd^{3+}/Cm^{3+}–H^+–Mg^{2+}–OH^-–Cl^-–NO_3^-$ system are currently derived, based upon the proposed chemical model.**
- **Additional solubility experiments in $CaCl_2–Ca(NO_3)_2$ and use of advanced spectroscopic techniques (EXAFS/XANES) foreseen to confirm aqueous speciation.**

References

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Acknowledgements: M. Böttle, F. Geyer and E. Soballa are kindly acknowledged for their technical support during this study.