Impact of Reduced Regeneration Frequency on the Ion Exchange Equilibrium for Organic Matter and Inorganic Ions Removal

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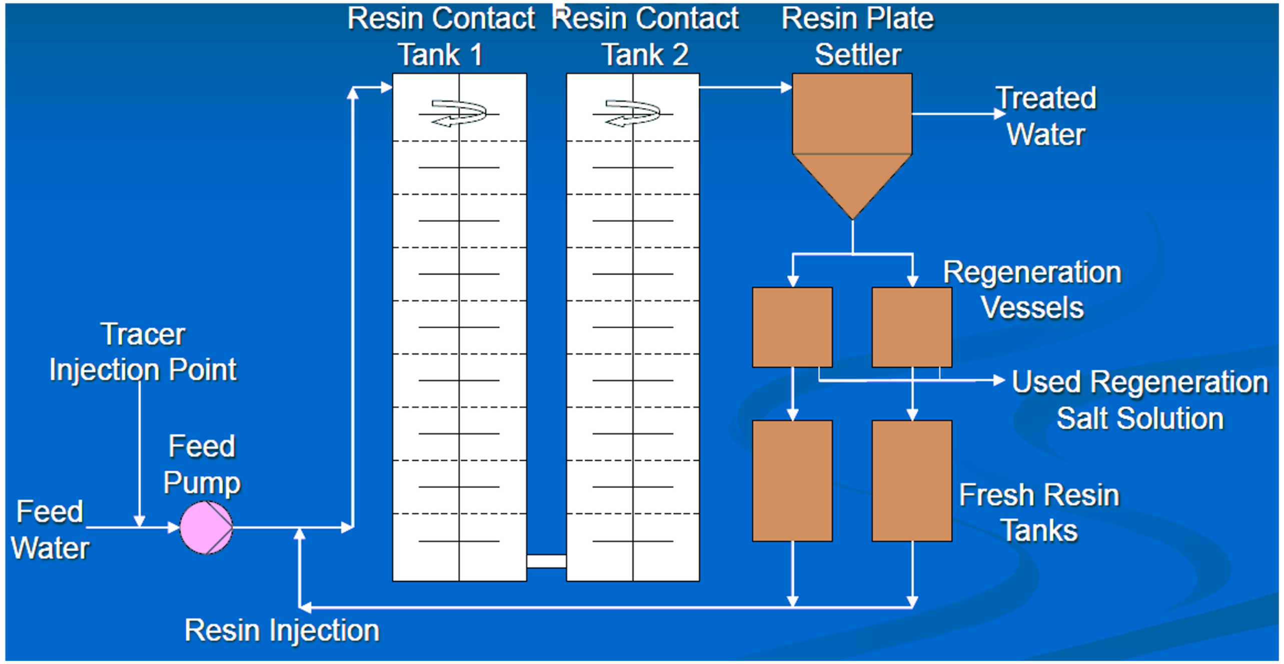
Why conducting this research?

Interest:

- Efficient **natural organic matter (NOM) removal** for drinking water production
- Efficient on both **hydrophobic and hydrophilic** rich water sources
- Used as a **front barrier** treatment for NOM, or in **combination with other processes**



Flow Diagram of the SIX® Process (Friend-Gray, 2010)

Limitations:

- high corrosivity indexes of the brine and treated water
- high volumes of brine and waste

Previous research: promising results at lab scale when using **bicarbonate as an alternative regenerant**.

Aim & Objectives

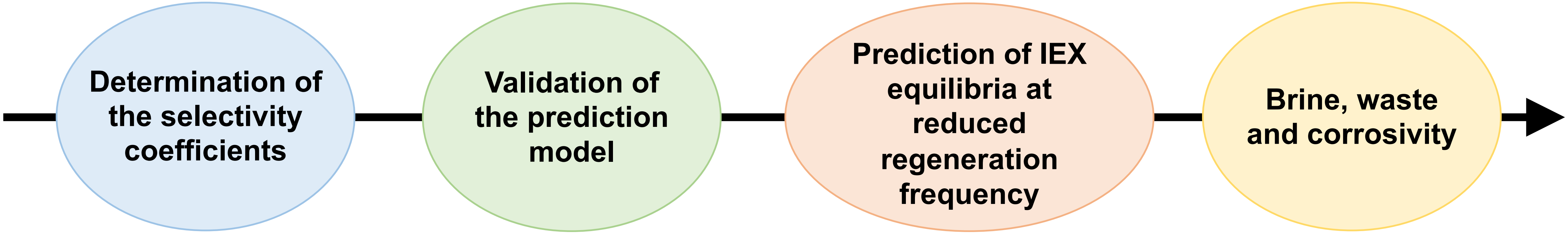
→ Determine **the impact of reduced regeneration frequency** on the ion exchange equilibrium and the subsequent influence on **brine use, waste and water corrosivity** using chloride and bicarbonate as regenerants.

Objective 1:
Determine the **selectivity coefficients** of NOM and inorganic ions.

Objective 2:
Develop and apply a **theoretical model to predict IEX equilibria** at reduced regeneration frequency.

Objective 3:
Establish the **implications of reduced regeneration frequency**.

Methodology



Selectivity coefficients & Model

Ion exchange resins reach an **equilibrium state** between ions in the solution and ions on the resin.

⇒ **Selectivity coefficients** describe the affinity for the resin.
⇒ Model built in **Matlab**.

$$n\,\mathrm{Cl} - R + B^{n-} \leftrightarrow B - R_n + n\,Cl^-$$

$$K_{X\backslash Cl} = \frac{[Cl^-]\,[X-R]}{[X^-]\,[Cl-R]}$$

$$K_{Y\backslash Cl} = \frac{[Cl^-]^2\,[Y-R_2]}{[Y^{2-}]\,[Cl-R]^2}$$

Prediction of IEX equilibrium for resin initially saturated **with one ion** (Cl^-):

$$[X^-] = \frac{[X^-]_0}{1 + \frac{K_{X\backslash Cl}\,\alpha\,\mathrm{EC}}{[Cl^-]_0 + \mathrm{EC}(1-\alpha)}}$$

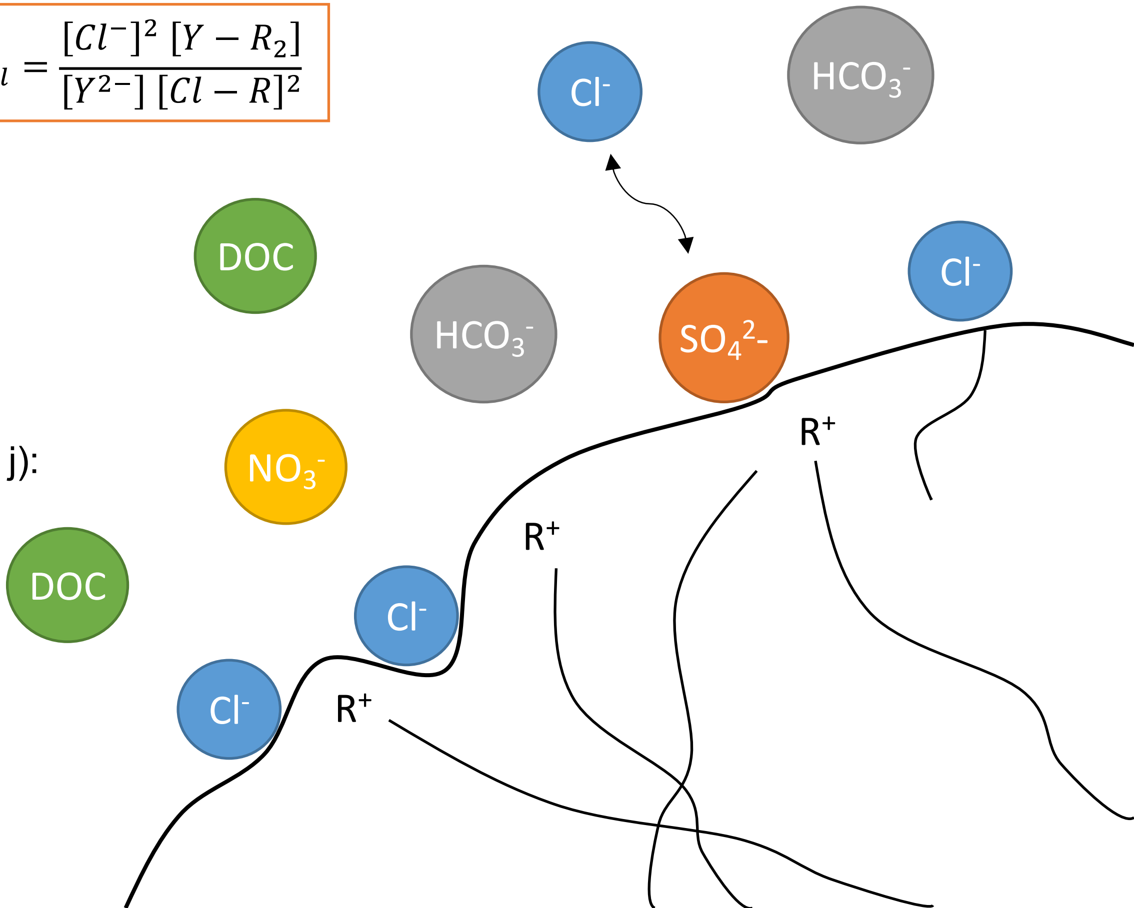
$$[Y^{2-}] = \frac{[Y^{2-}]_0}{1 + \frac{K_{Y\backslash Cl}\,(\alpha * \mathrm{EC})^2}{\left([Cl^-]_0 + \mathrm{EC}(1-\alpha)\right)^2}}$$

Prediction of IEX equilibrium for resin saturated **with more than one ion** (cycle j):

$$[X^-]_j = \frac{[X^-]_0 + [X-R]_{j-1}}{1 + \frac{K_{X\backslash Cl}\,\alpha_j\,EC}{[Cl^-]_0 + [Cl-R]_{j-1} - \alpha_j\,EC}}$$

$$[Y^{2-}]_j = \frac{[Y^{2-}]_0 + [Y-R_2]_{j-1}}{2 + \frac{K_{Y\backslash Cl}\,(\alpha_j\,EC)^2}{\left([Cl^-]_0 + EC(1-\alpha_j)\right)^2}}$$

→ Vary α or α_j until charge and mass balances match



Determination of the selectivity coefficients

Estimated using data from IEX jar tests with water from a lowland river in the UK.

Anion	$K_{i\backslash Cl}$	$K_{i\backslash HCO3}$
Cl^-	1	0.37
SO_4^{2-}	2.53	2.84
NO_3^-	0.32	0.36
HCO_3^-	0.45	1
DOC	0.51	0.57

Observations:

- Similar orders of selectivity for both resin forms
- Followed orders of % removal of each ion

Orders of selectivity:

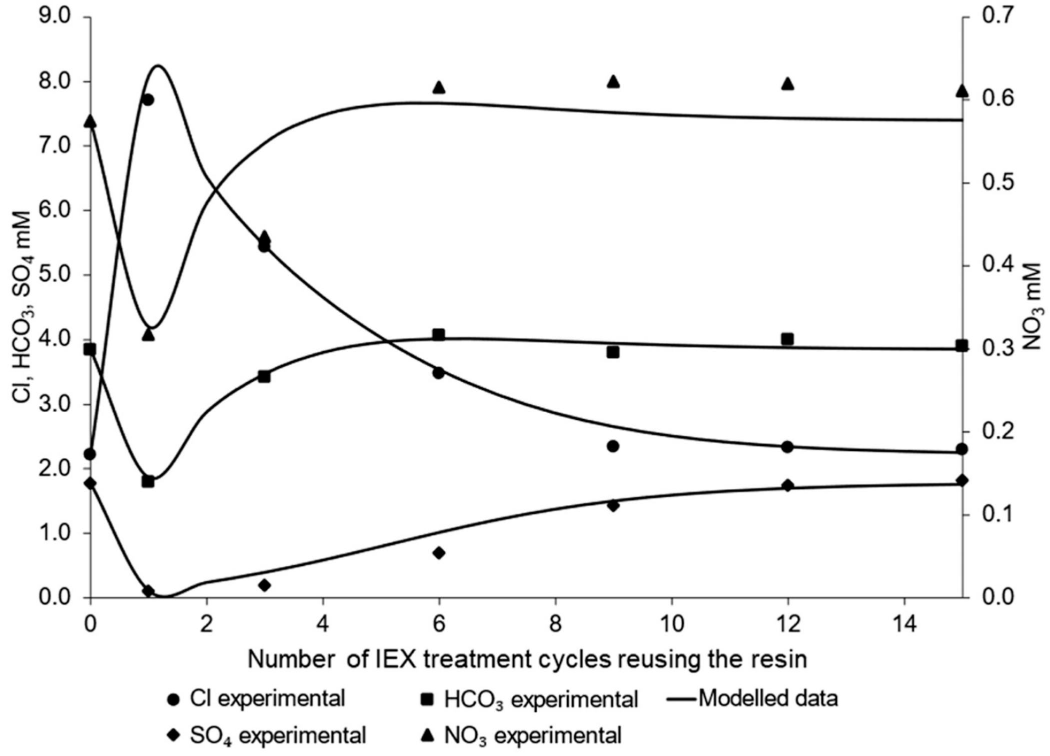
Cl-form resin: $SO_4^{2-} > DOC > HCO_3^- > NO_3^-$

HCO_3-form resin: $SO_4^{2-} > DOC > Cl^- \approx NO_3^-$

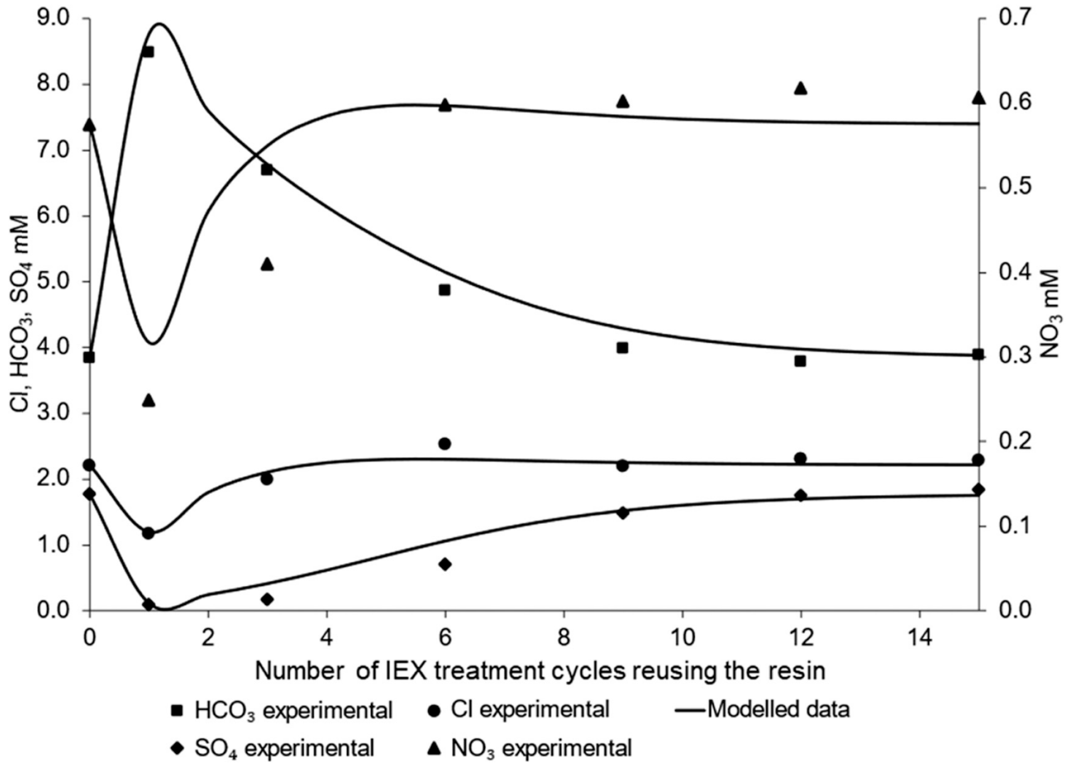
Validation of the model

- Model compared to 15 non-regenerated IEX jar tests with water from a lowland river in the UK.
- Model uses **constant K for all ions.**

Chloride-form resin



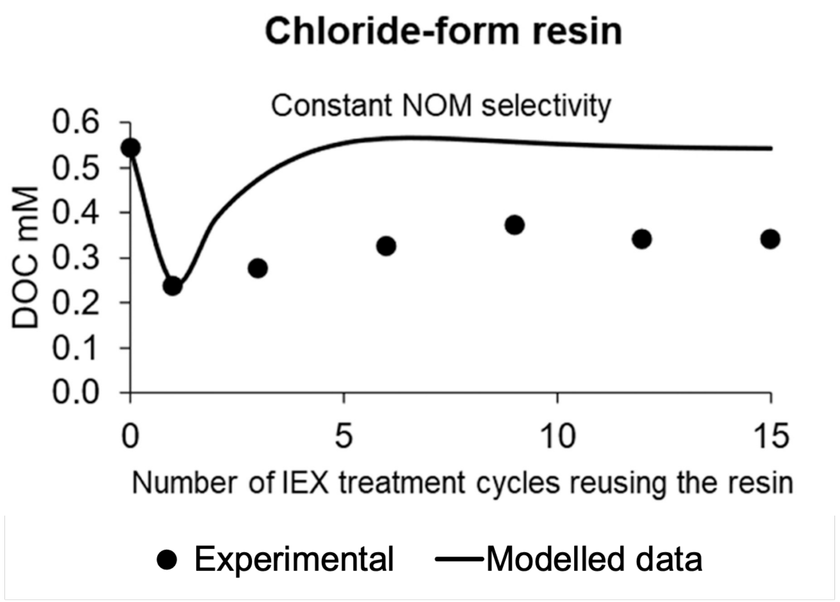
Bicarbonate-form resin

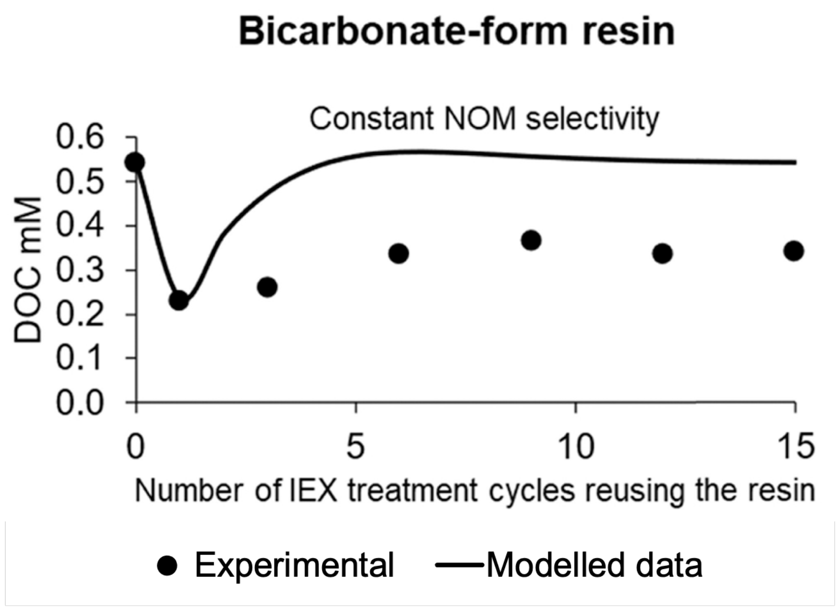


Observation:
- Good fit of the data to the model for inorganic ions

Validation of the model

- Model compared to 15 non-regenerated IEX jar tests with water from a lowland river in the UK.
- Model uses **constant K for all ions.**

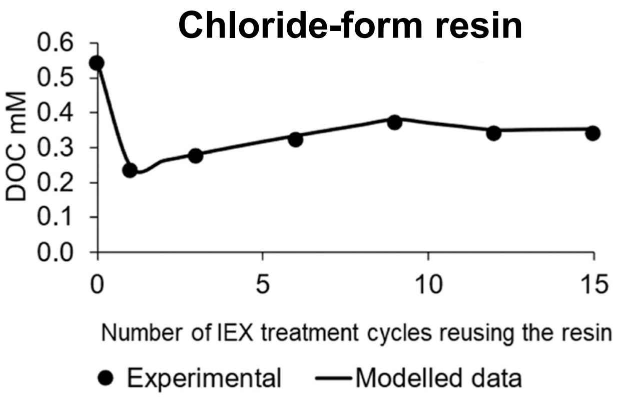


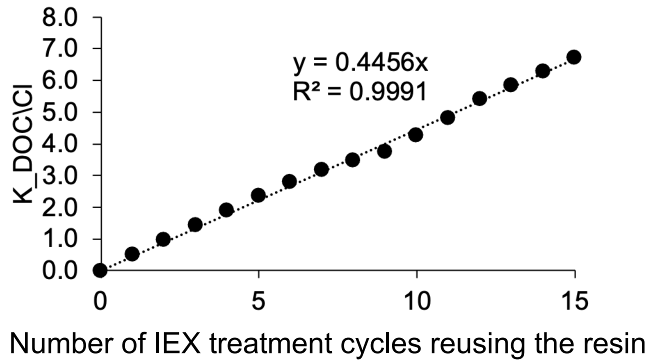


Observation:
- Data not matching for DOC

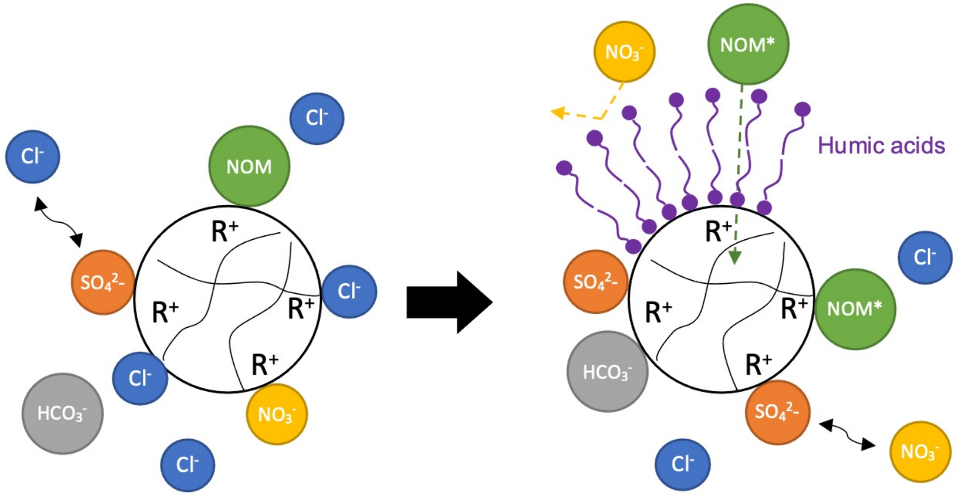
Validation of the model – Variable K for DOC

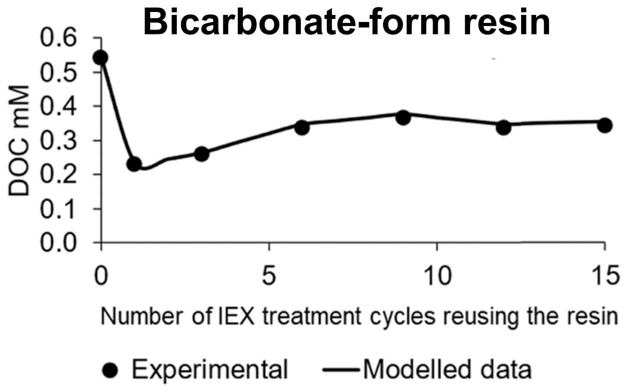
- Model compared to 15 non-regenerated IEX jar tests with water from a lowland river in the UK.
- Model uses **constant K for inorganic ions, variable K for DOC.**

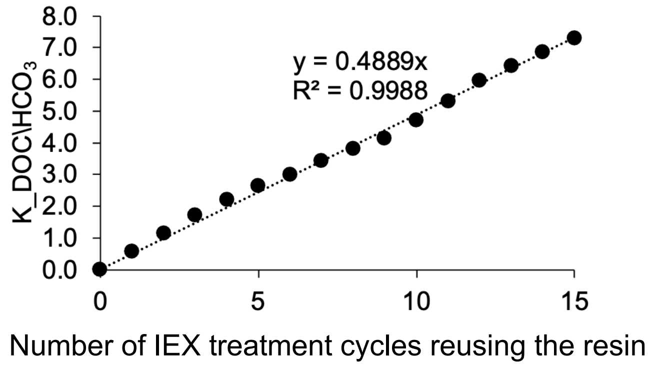




Selectivity for DOC changes over cycles





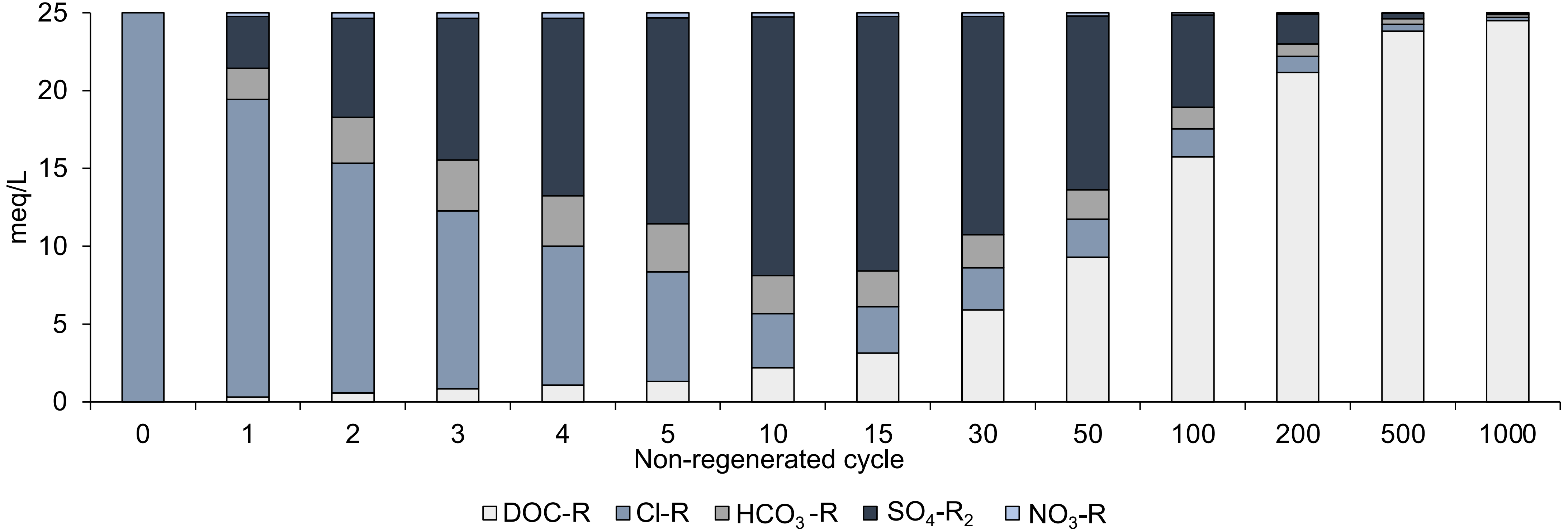


Selectivity for DOC changes over cycles

Possible explanation:
- The organic ions associate together
- 2 mechanisms take place for NOM removal:
  - **Electrostatic interactions**
  - **Physical adsorption (admicelle formation)**
- Contribution of the electrostatic interactions was overestimated

Prediction of IEX equilibria without regeneration

Model uses **constant K for inorganic ions, K for DOC increases linearly.**

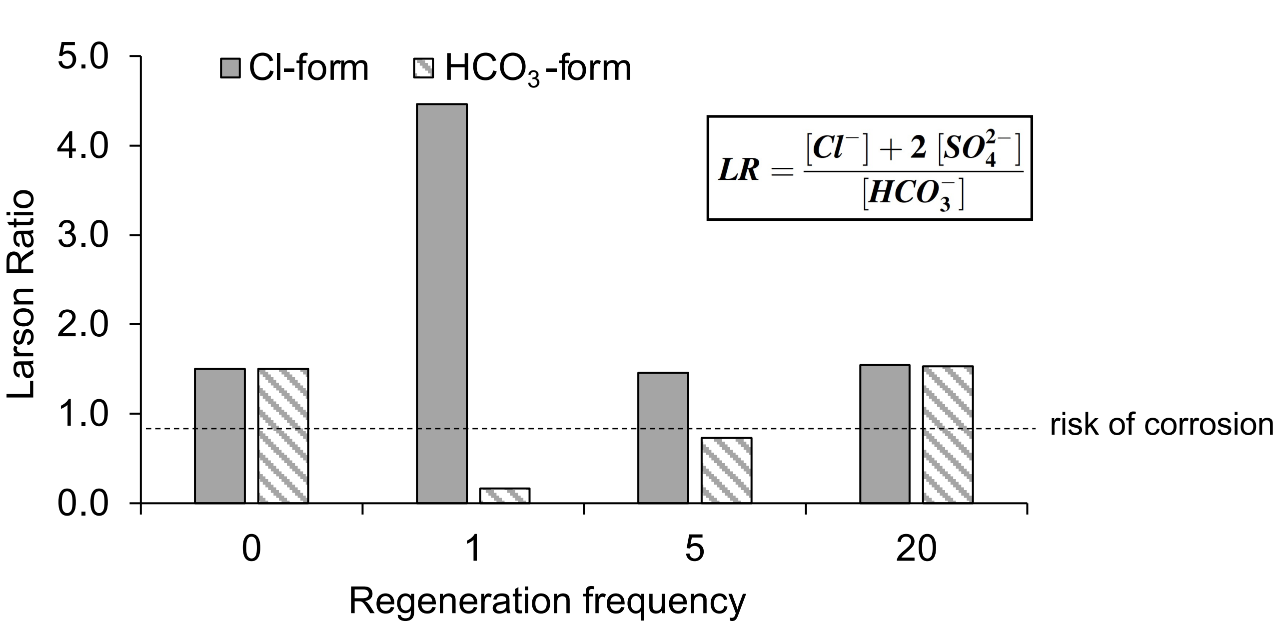


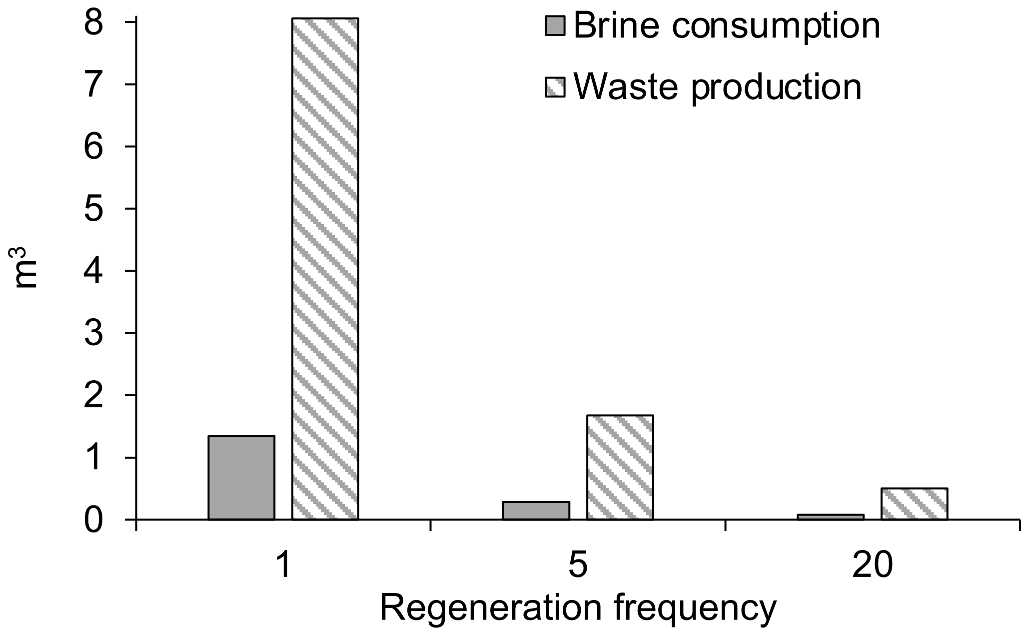
Observations:

- Secondary IEX occurs as resin is reused without regeneration.
- Resin saturated with NOM at cycle 1000.
- Similar results for HCO_3-form resin.

Performance of SIX at reduced regeneration frequency

NOM removal of scenarios studied :
- **56%** at cycle 1
- **41%** at cycle 5
- **34%** at cycle 20





→ Potential **increase in corrosivity** as bicarbonate-form resin is reused.

→ **Recovery of the adsorption capacity** might be **limited** at reduced regeneration frequency.

Conclusions

- Developed an IEX equilibrium prediction model that accounts for **changes in the resin loading**.
- Removal of DOC is complex because of **favourable interactions between organic ions** themselves.
- IEX resin reuse **reduces the treated water's corrosivity and brine and waste volumes**.
- Future research: **Quantify the contribution** of electrostatic interactions and physical adsorption in the removal of NOM.
- Future research: **Account for potential losses in adsorption capacity** at reduced regeneration frequency.

Thank you for listening

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References

Friend-Gray, O.P.;"Optimization of the Suspended Ion eXchange (SIX®) for Pre-treatment", Proceedings of the AWWA Water Quality Technology Conference, Savannah GA, November 2010.