Steady-State and Dynamic Modeling of a Solvent Extraction Process for Recovery of Rare Earth Elements

PROMMIS
Process Optimization and Modeling for Minerals Sustainability

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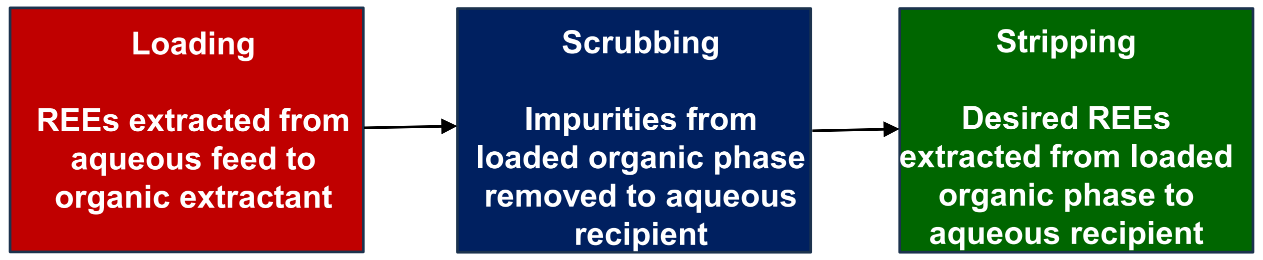
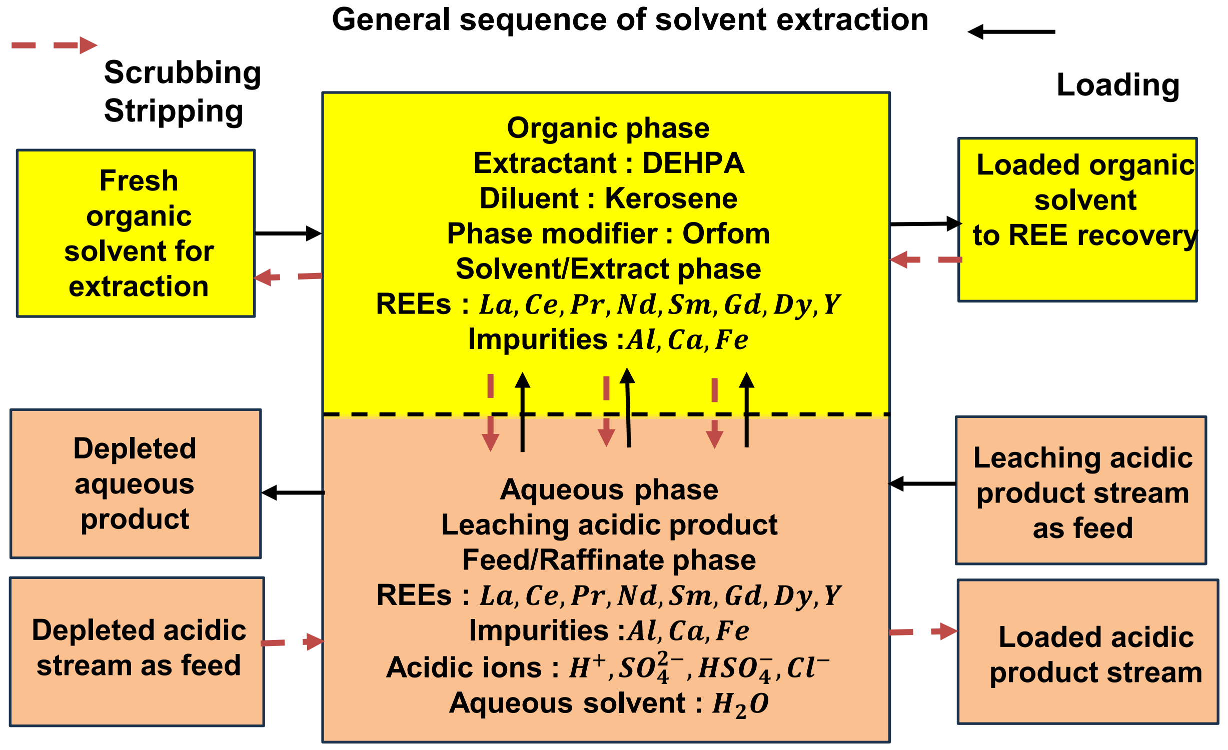
Solvent Extraction Process

Solvent extraction is a commonly used unit operation to extract the desired rare earth elements from the aqueous phase by using an organic extractant.



General sequence of solvent extraction



Solvent extraction equipment setup for the Nth stage[1]

Governing Equations for a Single Unit

Aqueous phase equations

$$V\theta_A \frac{dC_A}{dt}[I,t] = C_{AF}[I,t]v_{AF}[t] - C_A[I,t]v_A[t]$$
$$I = \{H_2O, Cl^-\}$$

$$V\theta_A \frac{dC_A}{dt}[A,t] = C_{AF}[A,t]v_{AF}[t] - C_A[A,t]v_A[t] \pm r_{inh}[t]$$
$$A = \{H, SO_4, HSO_4\}$$

$$V\theta_A \frac{dC_A}{dt}[E,t] = C_{AF}[E,t]v_{AF}[t] - C_A[E,t]v_A - r[t,E]$$
E = REEs and impurities

$$\left(\frac{C_A[H,t]}{MW_H}\right)\left(\frac{C_A[SO_4,t]}{MW_{SO_4}}\right) = \left(\frac{C_A[HSO_4,t]}{MW_{SO_4}}\right)(10^{-1.99})$$

Organic phase equations

$$V\theta_O \frac{dC_O}{dt}[S,t] = C_{OF}[S,t]v_{OF}[t] - C_O[S,t]v_O[t]$$
S = DEHPA

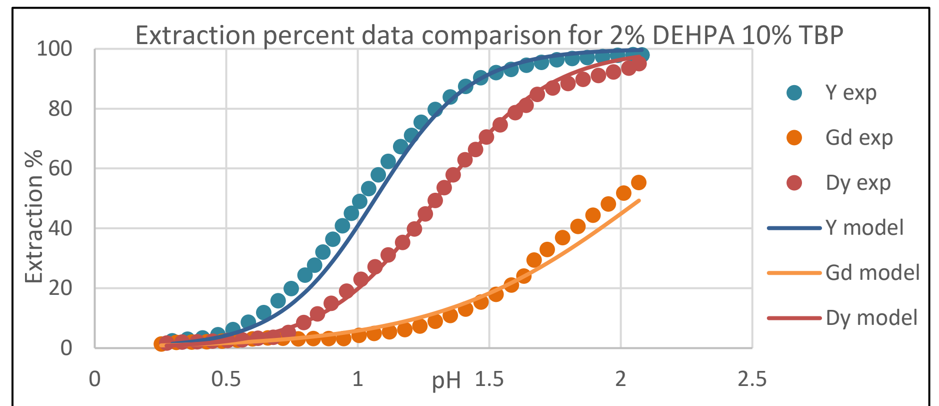
$$V\theta_O \frac{dC_O}{dt}[E,t] = C_{OF}[E,t]v_{OF}[t] - C_O[E,t]v_O + r[t,E]$$
E = REEs and impurities

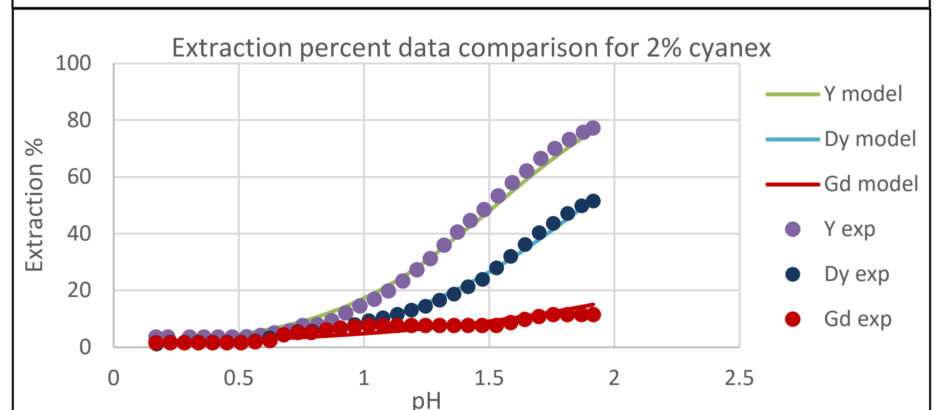
Distribution coefficient equation

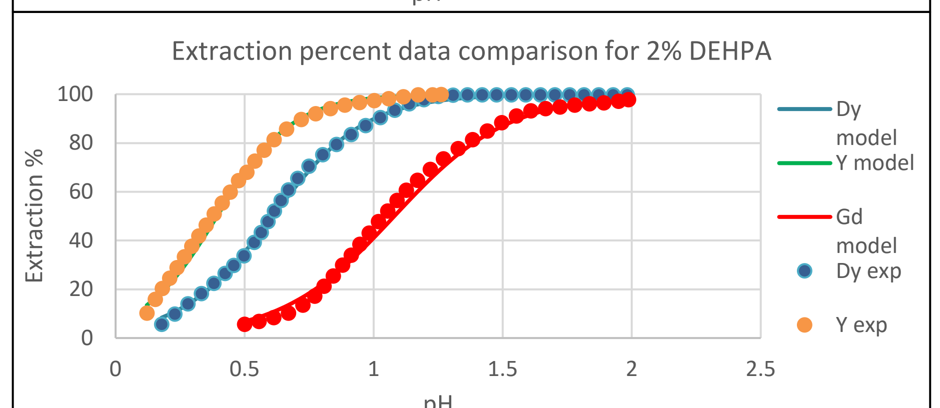
$$D[E]C_A[E,t] = C_O[E,t]$$

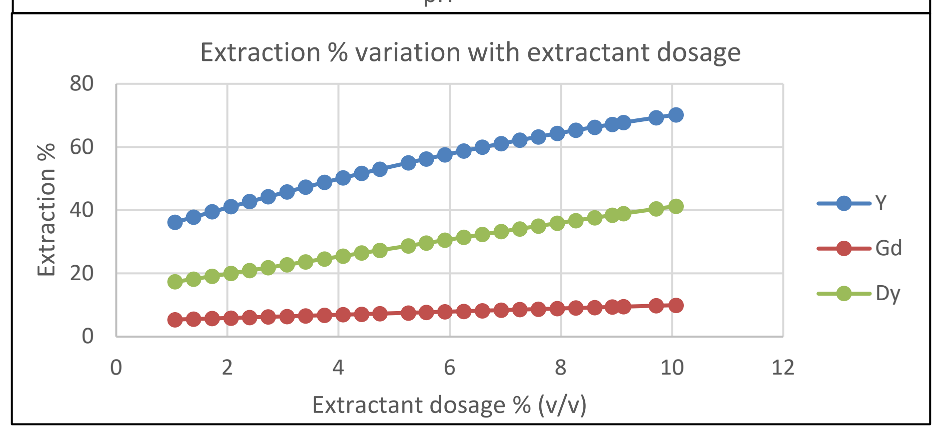
$$\log D[E] = (m[E])(pH) + B[E]$$
E = REEs and impurities

Performance Models and Flowsheet Development



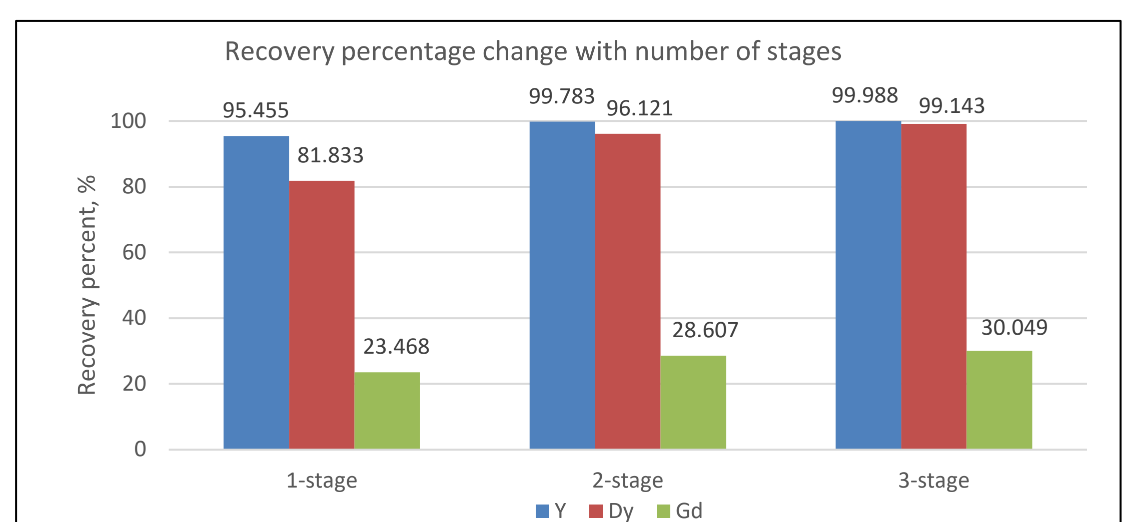




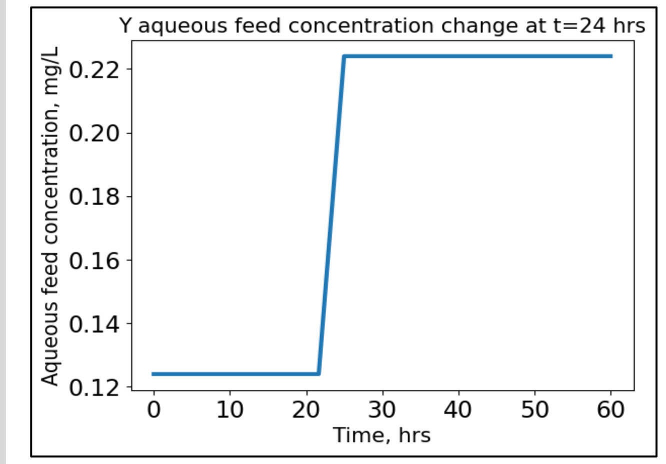


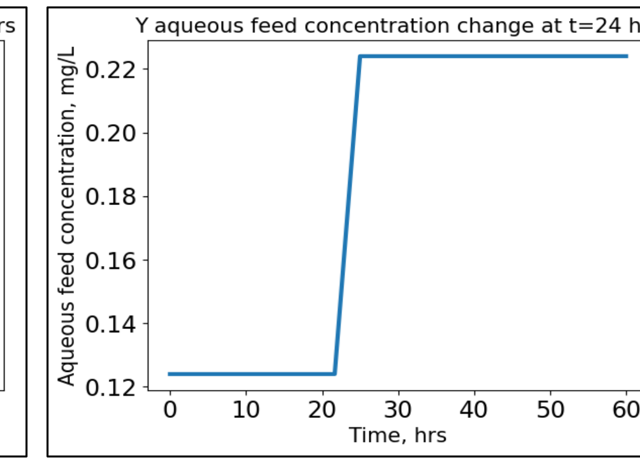
- Experimental data on the variation of the extraction percentage with respect to pH and extractant dosage have been obtained from the Univ. of Kentucky pilot plant phase 1 report.
- Correlations are developed for the distribution coefficient as a function of pH and extractant dosage.
- These correlations are developed for 6 REEs and for loading and stripping condition for three extractants- 2% DEHPA, 2% Cyanex, a mixture of 5% DEHPA and 10% TBP.
- The correlation is extrapolated to the system of 2% DEHPA and 10% TBP for 6 elements- Y, Nd, Dy, Gd, Sm, Ce.
- A flowsheet is developed by connecting multiple loading and stripping stages.
- Both steady-state and dynamic simulations are performed.

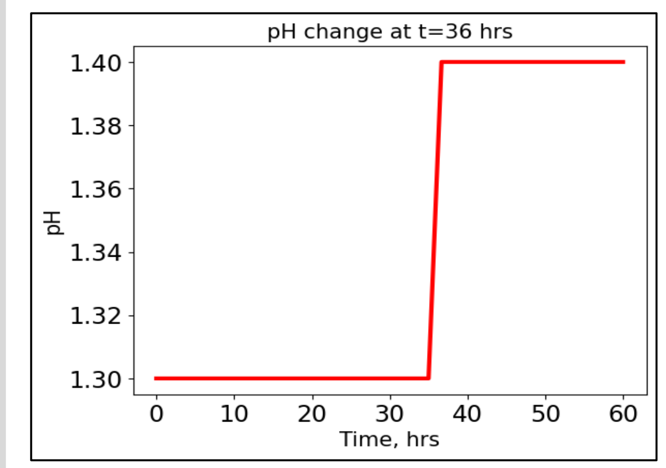
Variation in Recovery with Number of Stages

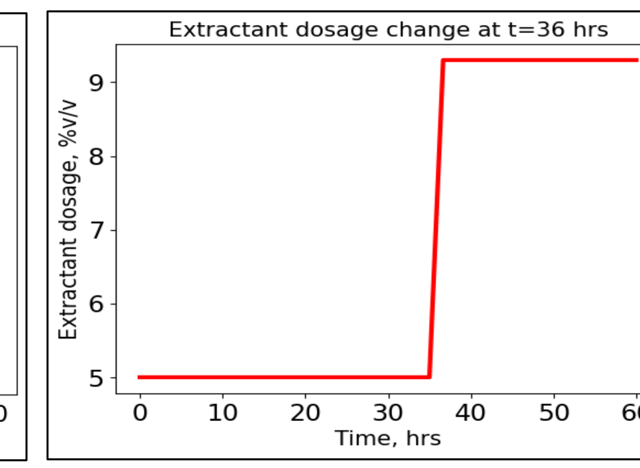


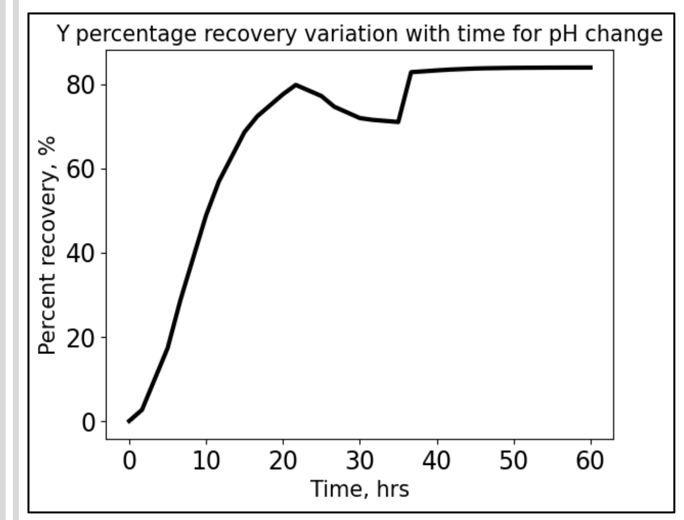
Dynamic Operation and Disturbance Rejection

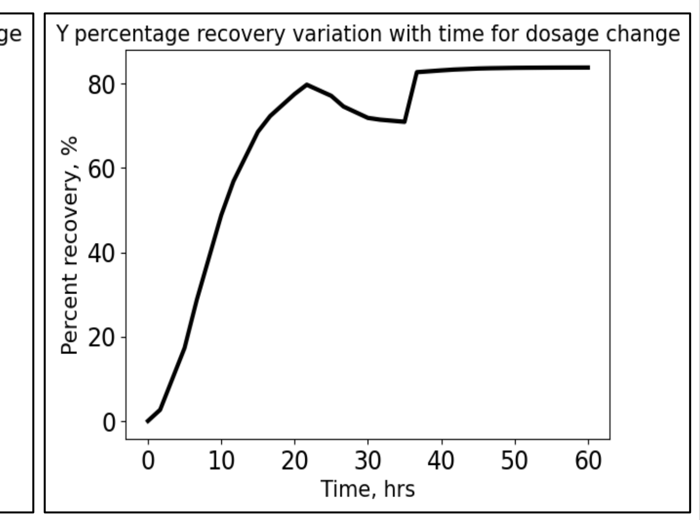












Future Work

- Regulatory and supervisory level control systems will be developed, and servo control and disturbance rejection studies will be conducted.
- Dynamic optimization will be conducted by considering an economic objective.
- Detailed model of the membrane solvent extraction unit will be developed.

Acknowledgement

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References

1. Zhang, J.; Zhao, B.; Schreiner, B. *Separation Hydrometallurgy of Rare Earth Elements*; Springer International Publishing: Cham, 2016. https://doi.org/10.1007/978-3-319-28235-0.
2. Production of salable rare earths products from coal and coal byproducts in the U.S. using advanced separation processes phase 1 report Federal Grant number – DE-FE0029956

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