Application of Biosorption for REE Recovery from Coal Byproducts

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Team and acknowledgment



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Project Highlight

- List of Publications
 - 1. International Journal of Coal Geology, Volume 227, 103532, 2020 (Middleton et al, 2020)
 - 2. Separation and Purification Technology, Volume 241, 15: 116726, 2020 (Park et al, 2020)
 - 3. ACS Sustainable Chem. Eng. 2020, 8, 49, 17914–17922. (Alipanah et al, 2020)
 - 4. Environmental Science & Technology (10.1021/acs.est.0c08632) (Dong et al, 2021)
 - 5. Bulk Microbe Encapsulation (Manuscript in preparation).
- Patents
 - Scandium separation from rare earth element containing material (U.S. Provisional Patent Application No. 63/015,354; non-provisional to be filed by end of April)





Outline

- Biological materials are promising REE adsorbents (biosorbents)
- Engineering of REE-selective biosorbents
 - REE-selective biological ligands
 - Engineering platforms
 - REE recovery performance
 - TEA
- Summary and future plan



Biological materials are promising REE adsorbents (biosorbents)

- Inexpensive and readily available
- Effective in treating chemical contaminants including heavy metal pollutants
- Contain high-density of functional groups for metal binding











However... most existing ligands suffer from low binding selectivity toward REEs

Engineering biosorbents to improve REE selectivity

Laboratory screening



Peptide emits luminescence upon Tb binding

Silvaggi, et al, J. Am. Chem. Soc. 129, 7114-7120 (2007)

Look deep into nature...



Bacterium Methylobacterium extorquens living on REE

Ref: Elizabeth Skovran, and Norma Cecilia Martinez-Gomez Science 2015;348:862-863



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Biological ligands, LBT and LanM, bind REEs with high affinity and selectivity





Lanthanide binding tags and lanmodulin bind REEs with high affinity



Refs: Nitz et al., 2004 ٠ Deblonde et al, 2020

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Ref: Deblonde et al, ACS Inorganic Chemistry, 2020



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A selective biosorption approach for REE recovery



Refs:

- Park et al, ES&T 2017;
- Park et al, Separation and Purification Technology, 2020



REE-binding ligand immobilization for column purification

Biological approach





Chemical approach

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Refs: Brewer et al, ES&T 2019; Dong ES&T 2021





Three microbe encapsulation approaches developed

1. PEG microbead encapsulation

Pros:

- o Confined spherical structure
- o Chemically stable

Cons:

- o Extra washing step required
- Relatively low loading capacity
- o Low mechanical strength



Environmental Science & Technology **2019** 53 (23), 13888-13897.

2. Silica sol-gel encapsulation

Pros:

- o Low cost
- o Easy fabrication
- High loading capacity

Cons:

- o Irregular shapes
- o lower column stability



Environmental Science & Technology, 2021 (10.1021/acs.est.0c08632) ACS Sustainable Chem. Eng. 2020, 8, 49, 17914–17922

3. Bulk PEG encapsulation

Pros:

- Emulsion free fabrication
- o Scalable fabrication
- o High loading capacity
- o Chemically stable

Cons:

o Irregular shapes



Manuscript in preparation.



Two-stage sequential recovery of Sc and Ln



- Sc recovery at pH 3Ln recovery at pH 5
- 2-stage strategy is not as profitable as onestage Sc extraction alone

Ref: Dong et al, 2021 ES&T. DOI: 10.1021/acs.est.0c08632



Sc recovery from lignite



- 18 mL column at an industrial relevant flow rate (0.001 m/s)
- Sc was concentrated 10-fold.
- Further removal of Fe and Th is needed



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Column Stability





- Citrate used for Sc recovery and column regeneration
- In the second second





Adsorbent reuse time	Pre-processing cost (\$/kg Sc)	Biosorption cost (\$/kg Sc)	Post-processing cost (\$/kg Sc)	General & indirect cost (\$/kg Sc)	Sc production cost (\$/kg)
1	\$394	\$32,565	\$294	\$8,291	\$41,543
10		\$911		\$734	\$2,333
100		\$594		\$652	\$1,934
200		\$578		\$648	\$1,913
300		\$573		\$646	\$1,906
400		\$570		\$645	\$1,903
500		\$568		\$645	\$1,901
1,000		\$565		\$644	\$1,896

- Production cost with North Dakota lignite containing 35 ppm scandium (90% Sc recovery from biosorption).
- Sc recovery cost depends on column re-use time



Lanmodulin enables highly selective REE extraction from lignite



 Lanmodulin has sufficiently high affinity and selectivity for both Sc and REE recovery from coal byproducts.



Final deliverable: Proof-of-concept, 2-stage Sc, REE+ Y extraction demonstration in a bench scale packed-bed bioreactor with at least one coal feedstock

- Scalable cell-based biosorption column for Sc recovery
- LanM-based biosorption column for Ln recovery
- Conversion of liquids to solids and product specs (in progress)





