Circum-neutral Weathering of Rare Earth Element (REE) Containing Minerals

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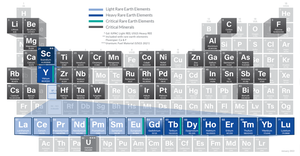
INTRODUCTION



Courtesy: U.S. NETL

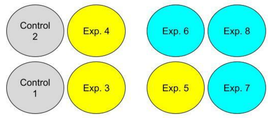
Courtesy: Financial Times

Rare earth elements (REEs) are vital in renewable energy systems, national defense, and aerospace. These have powerful magnetic properties due to their unpaired 4f electrons. REE are used in devices like wind turbines and magnets. The **REE Permanent Magnet Industry could reach $32.86 Billion by 2027** (BusinessWire, 2021). China controls 80% of the worlds available REE supply and the U.S. needs new sources of domestic REE. A bio-mining agent that extracts and separates REE without the use of acid could **mitigate acid mine drainage** from large mines and **provide sustainable mining.**

Hypothesis: Warmer bioreactor conditions will cause *Shewanella oneidensis* to extract greater Rare Earth Elements than 22 Celsius.

METHODOLOGY

Figure 1- Eppendorf Bioreactor setup. C=grey. 37C in yellow and 22C in blue. The bioreactors were setup manually and programmed to operate for 7 days.



1. *S. oneidensis* grown in Luria Bertani medium in 1L bottle and on lab benchtop. Centrifuged at 6,000 rpm, 6 min. to get concentrated cells, 1mL of cells added to experimental bioreactor.
2. Bioreactors Extraction: 250mL Shewanella Minimal Media (Na Acetate, No AQDS), 15.0g coal ore. 1mL bacteria to experimental vessels and no bacteria to control vessels. 1,2 = Controls at 37 C, 3-5=37 C, 6-8=22 C
3. Bioreactor program conditions: Rotors 200rpm, 5% CO2, 95% N2 0.50 sL/Hour; 7 Days anaerobic run
4. Final media filtration 0.22µm filter, 10 mL media sample for ICP-MS
5. ICP-MS chemical analysis for individual REE analysis, parts per billion
6. Cells filtered through 500 micron filter to then be nanopure water rinsed and finally 10% HNO3 rinse to determine if are REEs adsorbed

Coal Ore in Bioreactor Vessels

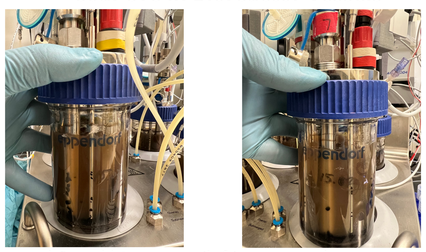


Figure 2- Experimental 6 coal bioreactor (left) compared to experimental 7 coal bioreactor (right). Yellow-brown media coloration seen in coal extraction. Can see coal positions in media and some are trapped on probes. Cell formation in coal sediment at bottom of bioreactor vessel.

RESULTS

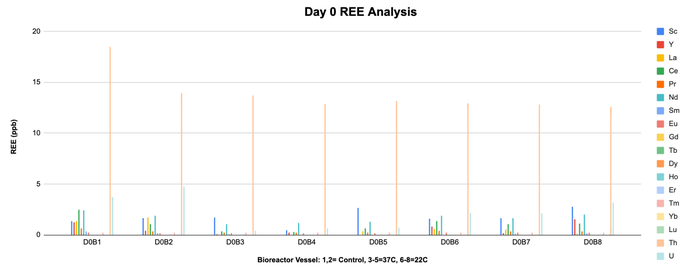


Figure 3: Low Day 0 REE concentrations. **No presence of Gd, Tb, Dy, Ho, Er, Yb or Lu**. All under 0.

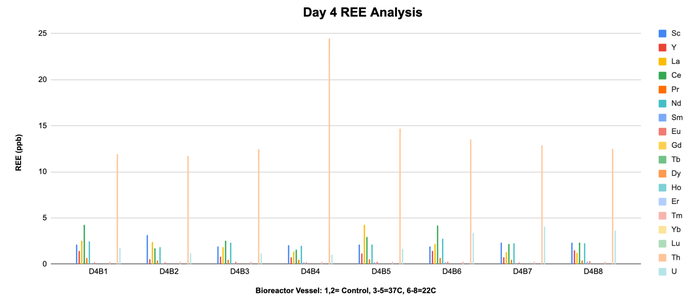


Figure 4: More REEs released into solution. For some REEs, the 22C vessels are extracting more. For Nd, 37C has 2.3, 1.9, 2.1 and 22C extracted 2.7, 2.2, and 2.2 ppb.

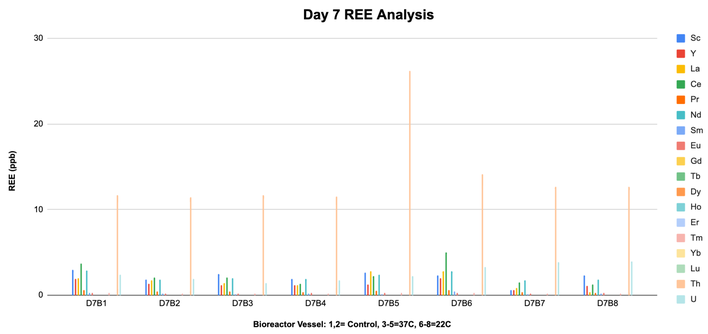


Figure 7: Final REE analysis. .Controls averaged 26.152 ppb total REE, 37C avaeraged extraction 28.69 ppb and 22C averaged 27.06 ppb.

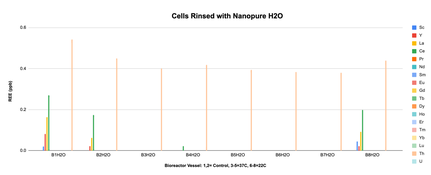


Figure 7: REE Data from ICP-MS, nanopure H2O rinse of cells to determine if REEs will be washed off the cell surface. This is also done to remove any debris from the cells. Bioreactor 1, 2 and 8 showed some release of REEs.

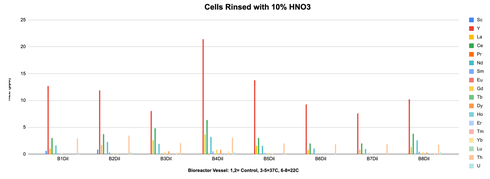


Figure 8: Cells washed with 10% HNO3; approx. -0.15pH. Concentrations in ppb are much higher and more REEs are released into solution. 37C vessels 4 and 5 released the greatest REEs.

DISCUSSION

- **Greater REE was extracted from coal ore than clay ore: due to REE content and mineral matrix able to hold more REE**
- In coal ore, the greatest extraction was with, Sc ave.
- In coal ore, the least extraction was with Lu and Tm, 0.01-0.1 ppb range
- In clay ore, Tb, Th, and Lu were the least extracted; followed by Ho and Tm also low extraction (less than 0.002)
- P value from ttest between Sc experimentals Clay:Coal 5.0588x10^-6
- Extraction of REE from coal controls may mean there are pre-existing microbes and fungi; natural occurring from the original deposit
- pH data collected with electronic probes, calibrated at pH 4 & 7: pH data for both stayed above pH6.5 and less than 8.2, Circumneutral pH conditions
- **Stable pH indicates little to no use of acidolysis pathway and means redoxolysis & complexolysis pathways are active. pH 6.5-8.1**
- Final weight of coal ore was also weighed on a balance to determine % extraction.
- Final liquid leachate was evaporated to concentrated REEs and mixed metal products into a fine powder product from each vessel.

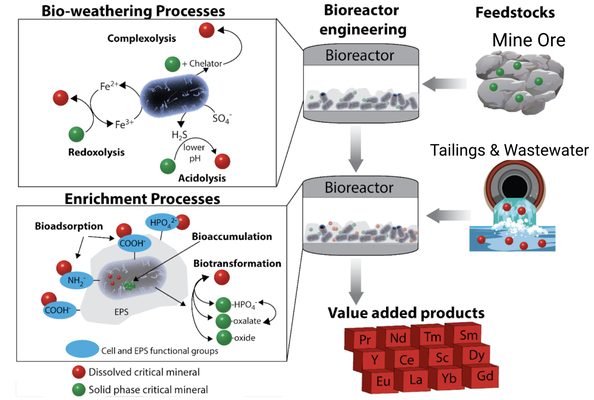


Figure 9 Bio-mining mechanism pathway may be linked to redoxolysis and complexolysis rather than acidolysis as the pH remained stable, indicating no-little acid production. Proposed pathways of bio-mining in bioreactor conditions.

FUTURE DIRECTIONS

- Scaling Up process, 1L bottles with 50-100 g ore
  - Mechanism elucidation, HPLC for siderophore anaylsis
- Reusing cells by acid washing and reintroducing cells to the bioreactor vessels at certain time points
- Multi-element analysis: Are the cells REE specific for binding or not?
- Test against aerobic and anaerobic cycling conditions as the microbe is a facultative anaerobic bacteria
- Cell culture exposed to light REEs vs heavy REEs to determine binding capabilities since here no heavy REEs in ore.

ACKNOWLEDGMENTS

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