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The Extraction of Rare Earth Elements from Appalachian Coarse Coal Refuse Through Heap Leaching

West Virginia Mine Drainage Task Force Symposium

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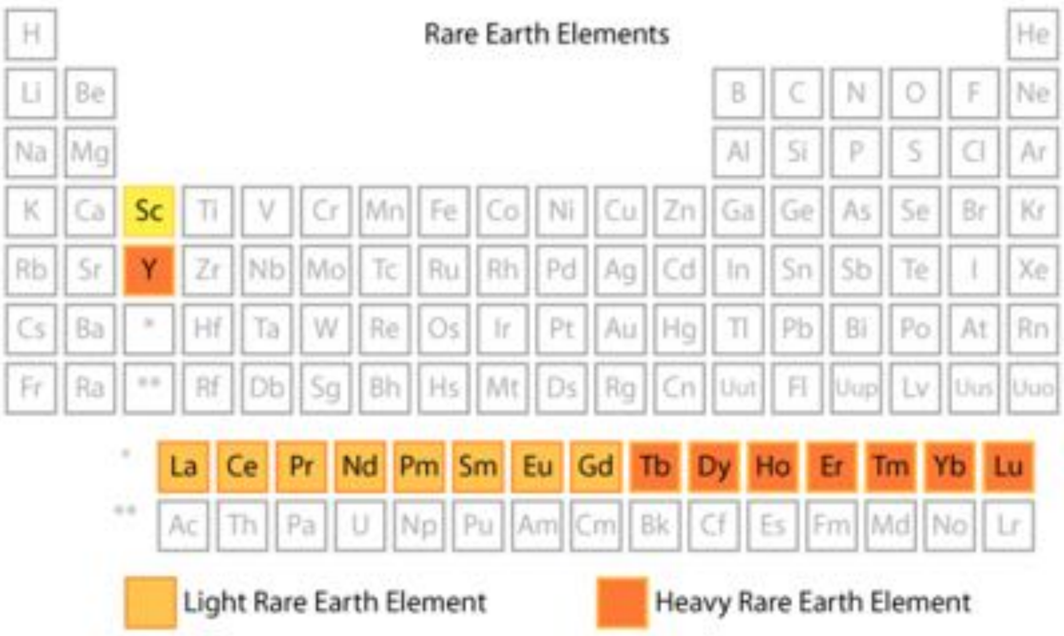
Background

- REEs are essential components of many high-tech applications such as green and renewable energies, batteries, phosphors, glass polishing, petroleum refining, and ceramics.
- Previous research has found that the majority of REEs are present in reject streams of coal preparation plants, especially coarse coal refuse (CCR).



Coint, N., & Dahlgren, S. (2019)

$$4FeS_2 + 15O_2 + 14H_2O \longrightarrow 4Fe(OH)_3 + 8H_2SO_4$$ (General reaction of pyrite oxidation)

Pyrite — Ferric hydroxide or iron hydroxide — Sulfuric Acid

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Main Goal and Objectives

Hypothesis

- Pyrite oxidation can be accelerated, and REE extraction from CCR can be enhanced through the recirculation of AMD.

Main Goal

- Evaluate the performance of heap leaching for the extraction of REEs from CCR.

Objectives

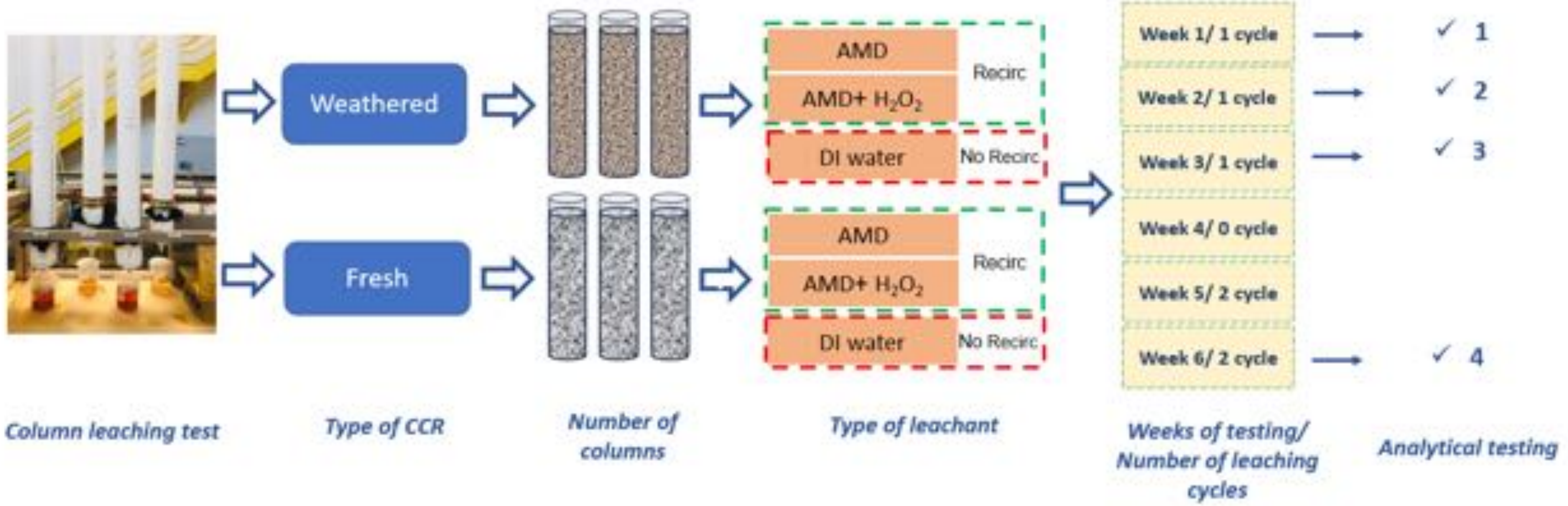
- Determine whether CCR could serve as a potential feedstock to extract REE.
- Determine the influence of key management and controlling variables.
- Identify the kinetics of REE release from CCR.

Methods

The Blacksville Number 2 Coal Mine (also known as "Monongalia County Mine")

Objective 1: Determine whether CCR could serve as a potential feedstock to extract REE.

Methods/ Lab Work



Type of CCR placed in each column and type of leachant used in the test.

Column Number	Type of CCR	Leachant Used	Column Name used in results
1	Weathered	Recirc AMD	1-AMD-W
2	Fresh	Recirc AMD	2-AMD-F
3	Weathered	DI Water	3-DI-W
4	Fresh	DI Water	4-DI-F
5	Weathered	Recirc AMD+H2O2	5-H2O2-W
6	Fresh	Recirc AMD+H2O2	6-H2O2-F

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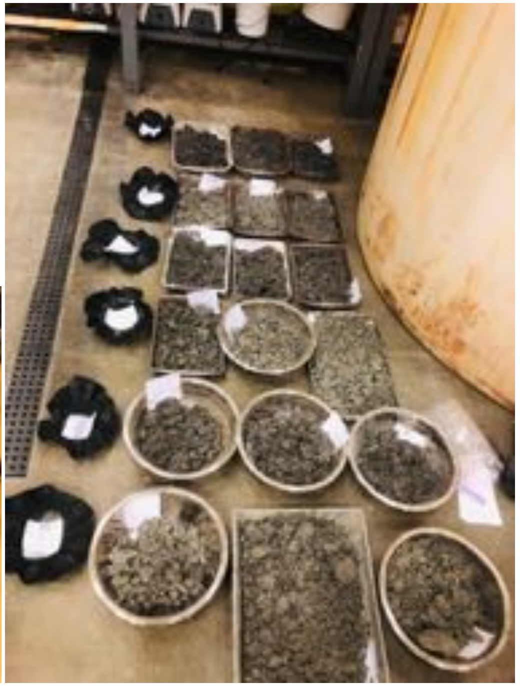
Methods/ Column Leaching Test



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Objective 2: Determine the influence of key management and controlling variables (e.g., flow rate and AMD recirculation).

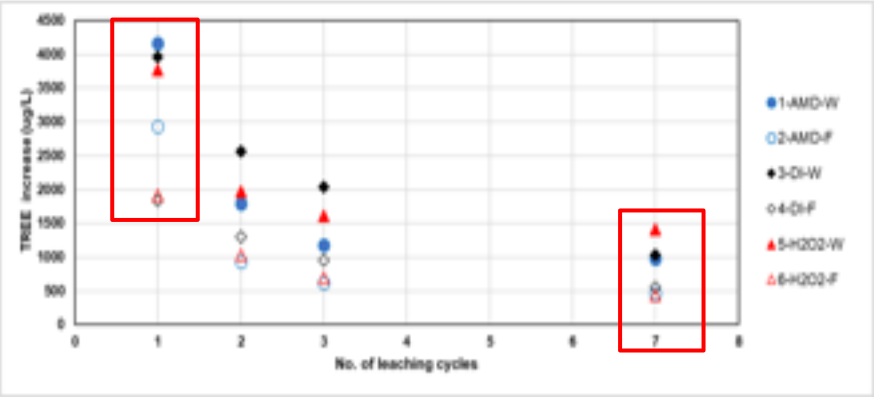
Results

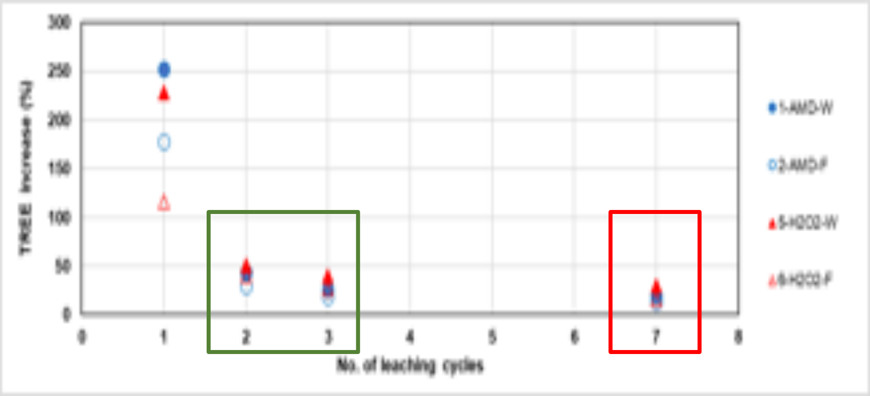
1- The first leaching cycle resulted in the highest percentage increase in TREE concentration in the collected leachate. 252%, 178%, 229%, and 116% in leachate collected from columns 1, 2, 5, and 6, respectively.

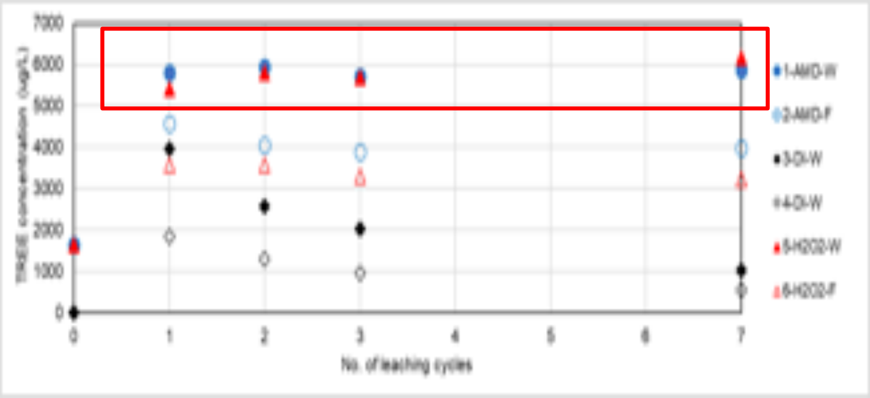
2- Multiple leaching cycles did not promote REE extraction.

3- Weathered refuse had higher leaching potential when compared to fresh CCR.

4- AMD as a leachant showed a better performance than DI water and AMD with added hydrogen peroxide.







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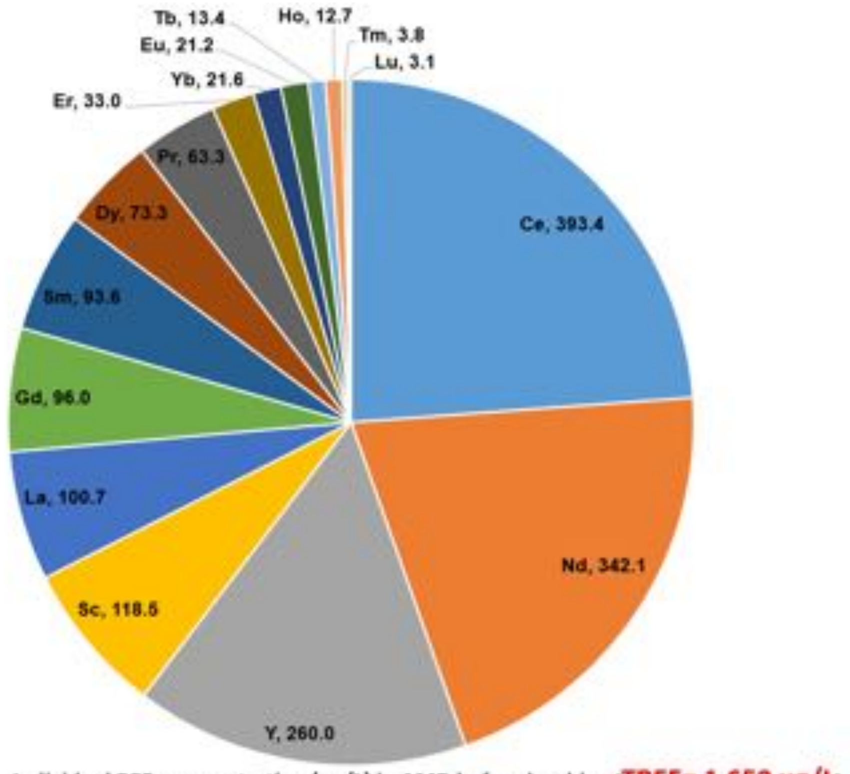
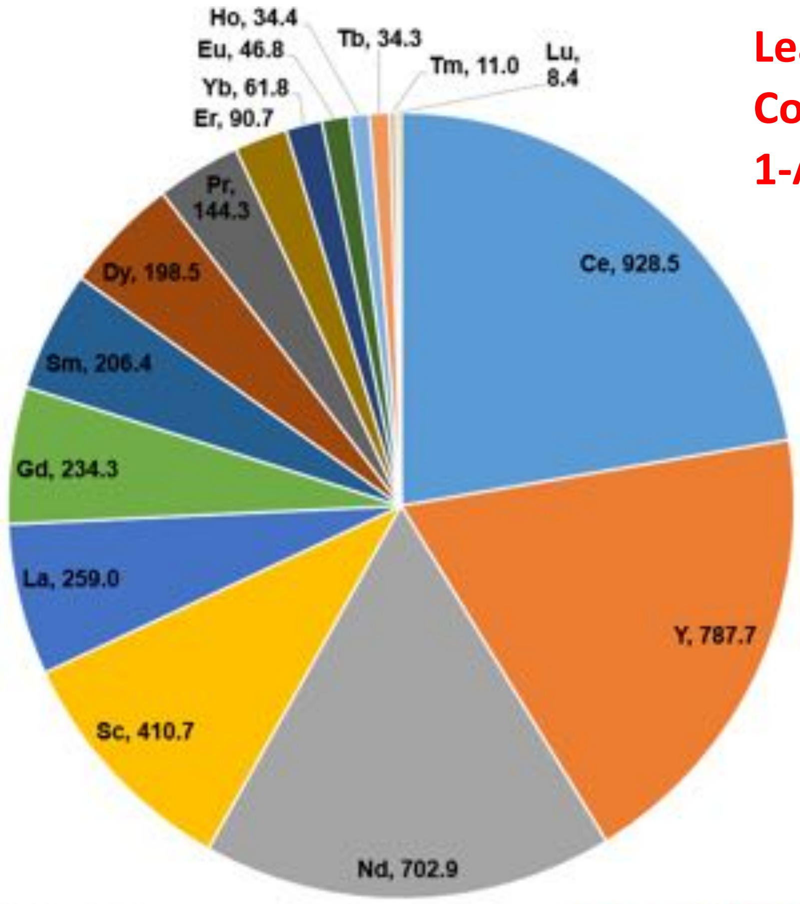
Results

Leachant



Individual REEs concentration (ug/L) in AMD before leaching (TREE= 1,650 ug/L)

Leachate Collected from 1-AMD-W (Week 1)



Individual REEs concentration (ug/L) in leachate (TREE= 4,160 ug/L)

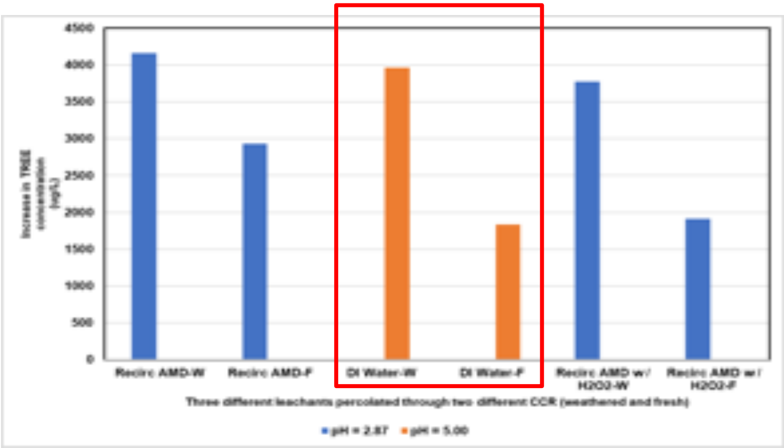
Results

5- Columns filled with weathered refuse had a lower flow rate than those filled with fresh refuse.

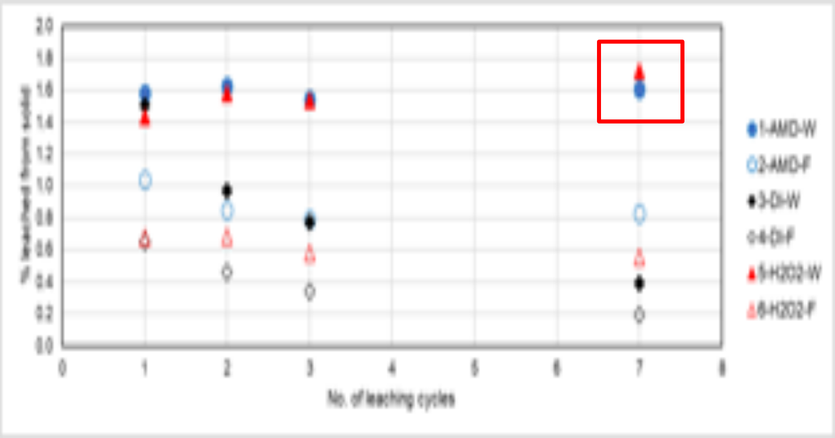
6- The pH value of around 4 for the DI water had no negative impact on the performance of leaching tests.

7- The highest percentage of TREE leached from solids was low (1.7%)

Average flow rate of leachant in six columns (weeks 1 through 6) in mL/min.



TREE concentration in leachate collected from six columns after the first leaching cycle (week 1)



Cumulative percent leached from solid (weeks 1 to 6).

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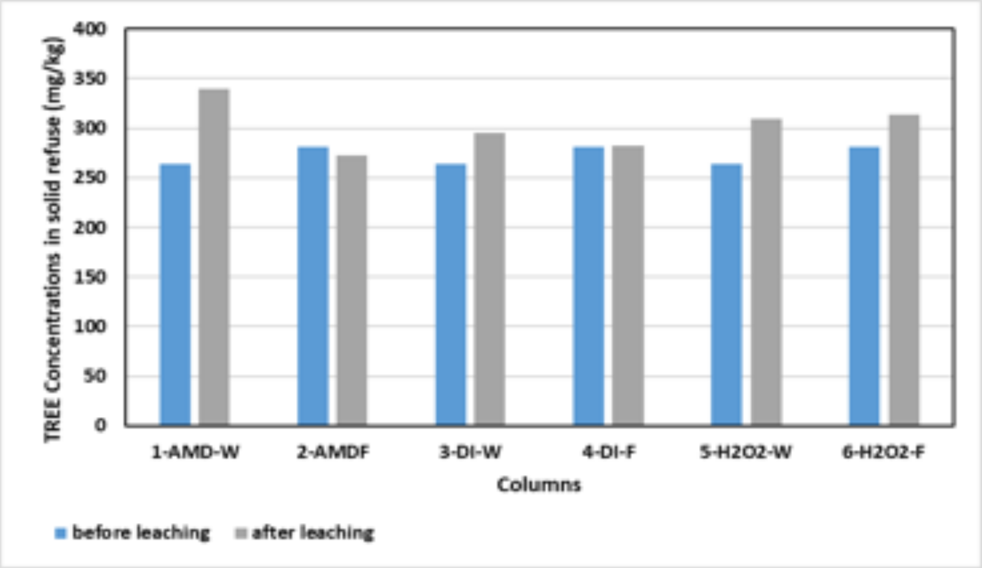
Results

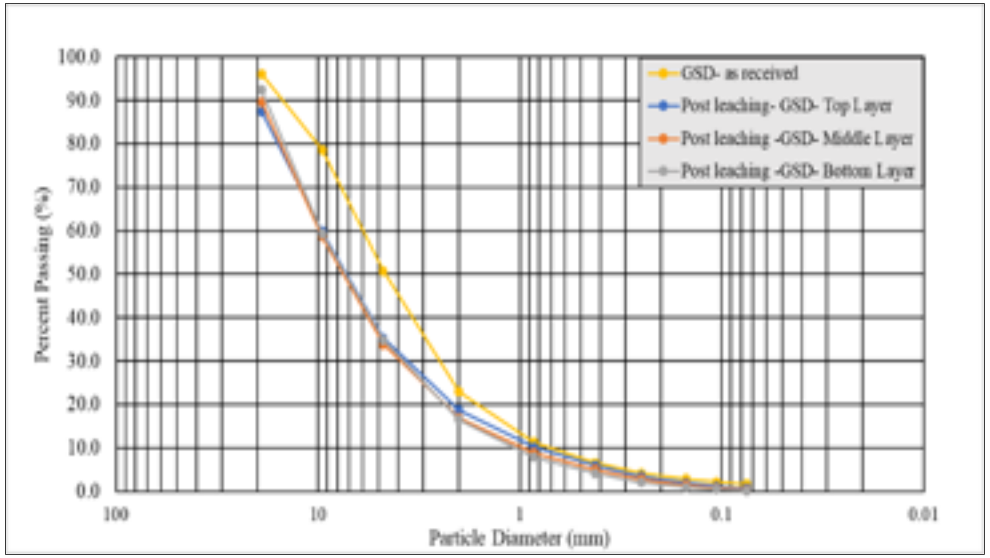
8- The amount of TREE concentrations in solids (post-leaching) showed some increase.

9- As a result of particle agglomeration, the GSD curve shifted to the left.

10- Similarly to TREE, TMM followed the same trends.

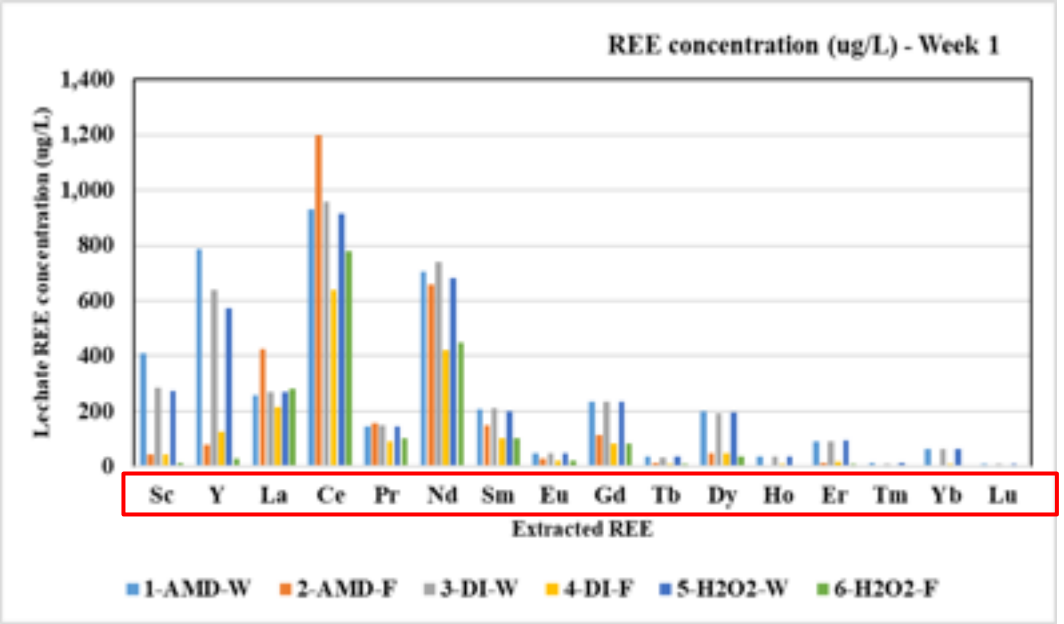


TREE solid concentration before and after leaching for six weeks

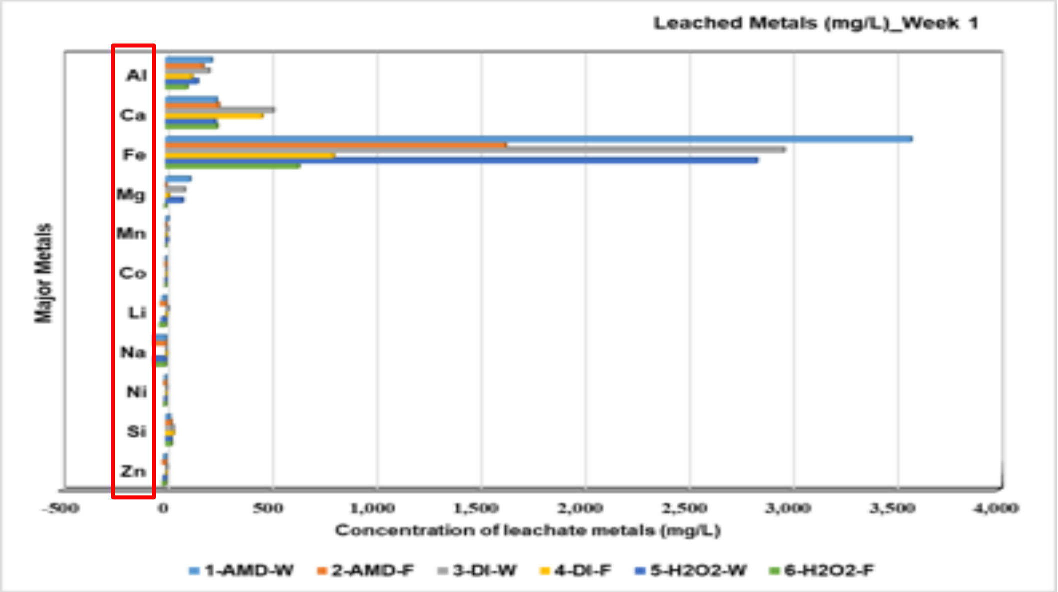


Post-leaching vs. as received GSD- Column: 1-AMD-W

Individual REE and MM Concentrations in leachate

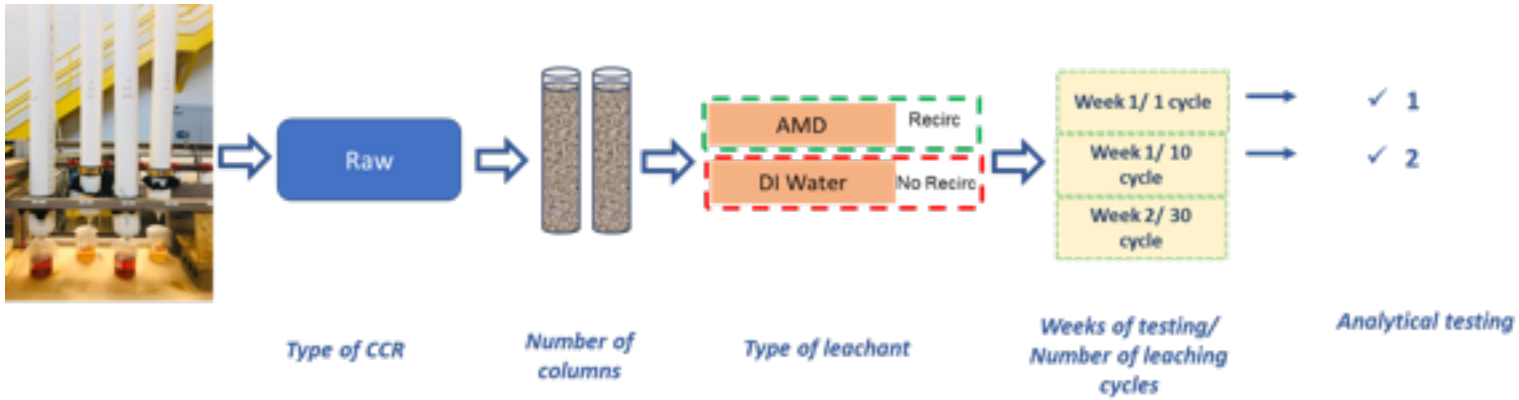


- ✓ Cerium (Ce), neodymium (Nd), and lanthanum (La) were the most abundant REEs in both weathered and fresh CCR. Whereas scandium (Sc) and yttrium (Y) were only abundant in the weathered coal refuse.



- ✓ Aluminum (Al), Iron (Fe), and Calcium (C) had the highest concentrations in leachate collected from the six columns.

Methods/ Lab Work

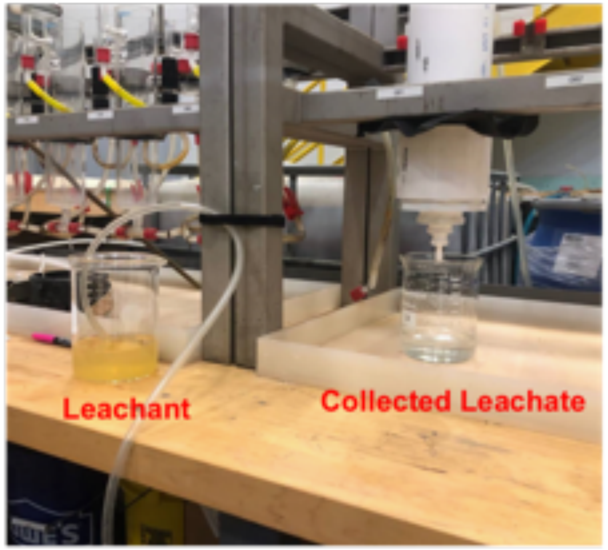


Loveridge Mine in Marion County, WV (Google Maps)

- Leachate samples were sent to the lab for analytical testing after cycles 1 and 10. Around 30 leaching cycles were completed for both columns, but the test was terminated after receiving the results of leaching cycle # 10.

Column leaching test setup (columns 1 and 2) filled with raw CCR

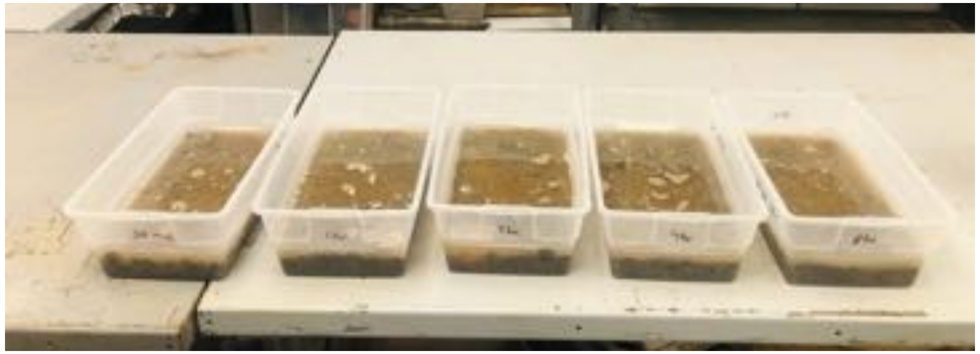
Results

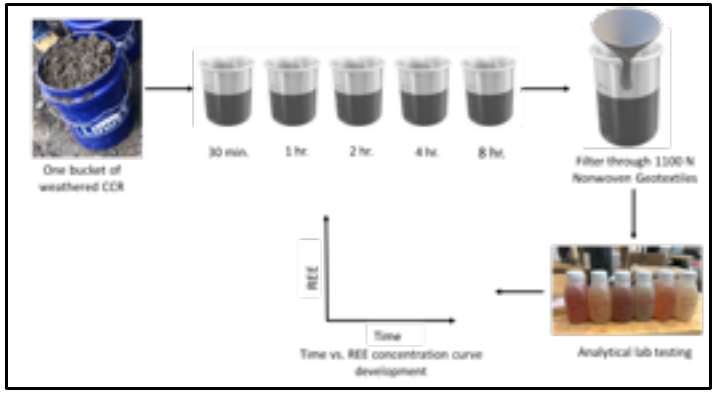


Leachant (AMD) going into column 1 (1-AMD-R) and collected leachate coming out of the column

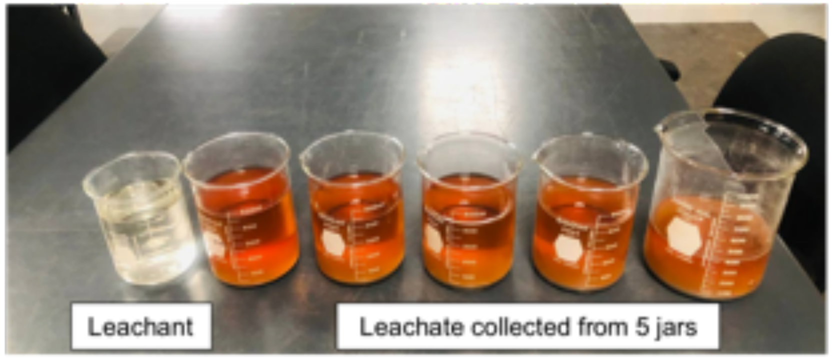
- Raw CCR refuse acted as a filter.
- pH readings of the leachate after each leaching cycle indicated that the solution was alkaline.
- The collected amount of REE was insignificant and declined after the first leaching cycle.
- Extended leaching cycles did not initiate the weathering process of the CCR nor promote REE extraction.

Weathered CCR - Jar Test





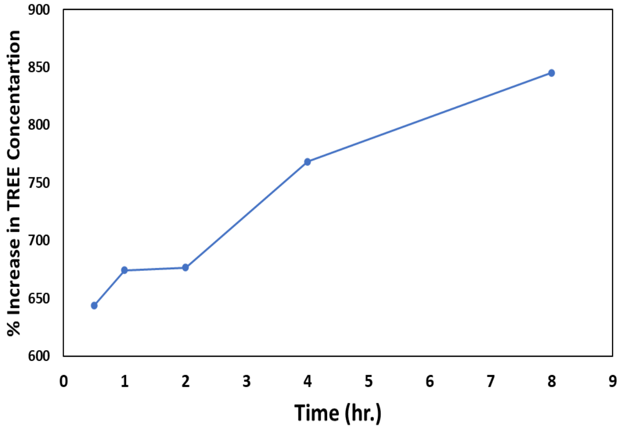
Weathered CCR jar test flow chart.

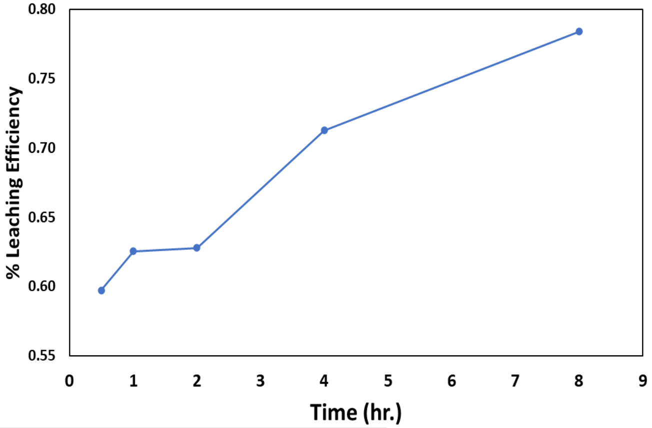


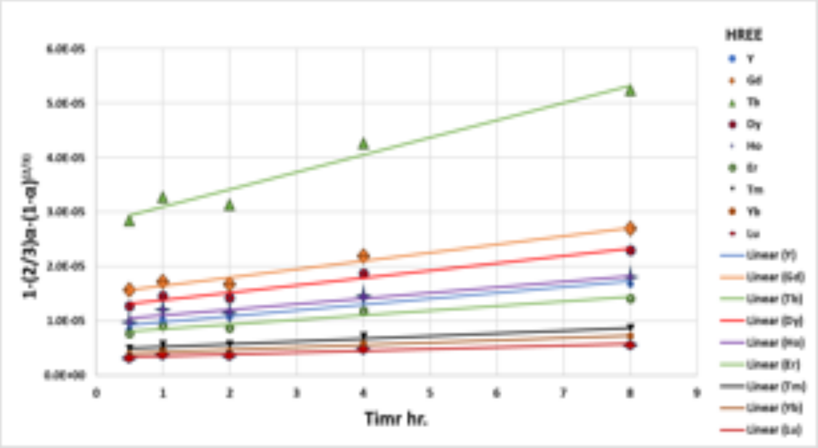
Objective 3: Identify the kinetics of REE release from CCR.

Results

✓ REE concentration in leachate increased as the contact time was extended.







Kinetic modeling of individual HREE

The square of the correlation coefficient (R^2) of three fitted models for individual HREE

	Chemically Controlled 1-(1-α)^(1/3)	Inner Diffusion Controlled 1-(2/3)α-(1-α)^(2/3)	External Diffusion Controlled α
HREE	R^2	R^2	R^2
Y	0.923	0.942	0.923
Gd	0.960	0.967	0.960
Tb	0.946	0.957	0.946
Dy	0.958	0.967	0.957
Ho	0.932	0.948	0.932
Er	0.932	0.946	0.932
Tm	0.954	0.967	0.954
Yb	0.934	0.949	0.934
Lu	0.916	0.931	0.916

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Interpretation of Results

First leaching cycle resulted in the highest % increase in TREE concentration!

- Hydrogen ion H+ quick reaction kinetics with REE-bearing compounds available at the surface of the solid particles resulting in the release of REEs.

Weathered had the highest potential for leaching!

- Pyrite oxidation has already taken place.
- Small particle size range due to fragmentation and slaking.
- Highest initial moisture content and degree of saturation.

Increased amount of TREE concentrations in solids (post-leaching)!

- REE sorbs back into the solid.
- Migration of REE from one spot in a sample to another.
- Variation in samples collected.

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Interpretation of Results

A pH of around 4 had no negative impact on the performance of leaching tests!

- CCR Stored acidity.

Columns filled with weathered refuse had the lowest flowrate!

- Weathered refuse has the smallest particle size range, fine particles can clog pores between large CCR particles resulting in decreased permeability.

Multiple leaching cycles did not promote REE extraction!

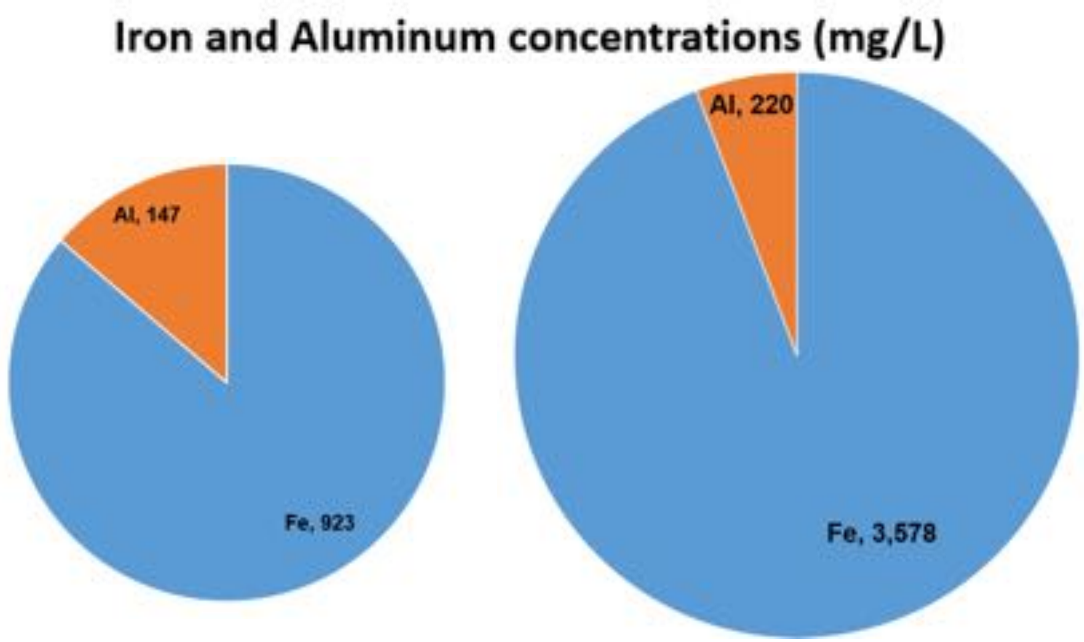
- The performed cycles did not provide all the needed factors for leaching.

Long contact time produces more REE!

- Diffusion is time dependent.

Conclusion

Conclusion: It is possible to extract REE from CCR by providing the necessary conditions and factors. The solid piles are expected to discharge their long-term pollutant in the process, which is an added benefit.



Before Leaching

After Leaching
Column 1-AMD-W

Future Work

- Conduct a CCR leaching test with a larger diameter column (e.g., 55 Gallon Tight Head Plastic Drum), so that the drum walls will have less restricting effect on the flow,
- The leaching process is time-dependent and should be promoted by providing the factors needed (e.g., humidified air) between flushing cycles,
- Grain size plays a very important role in the process, affecting the leaching efficiency; crashing the CCR might increase the surface area available for chemical reactions and REE liberation.

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Summary

Leaching of REE from Appalachian CCR

Objectives

Determine whether CCR could serve as a potential feedstock

Determine the influence of key management and controlling variables

- CCR type
- pH
- AMD recirc.
- H_2O_2 addition
- Contact time

Identify the kinetics of REE release from CCR

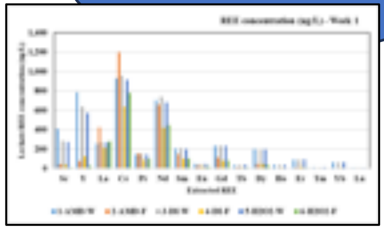
Methods

Column Leaching Test

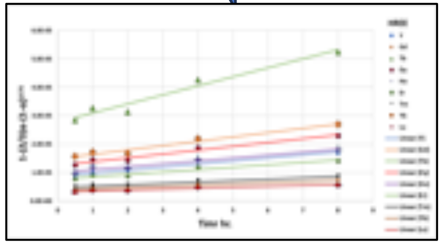
Jar Test

Results

1- … max TREE.
2- Weathered refuse had the highest leaching potential.
3- Multiple leaching cycles did not promote REE leaching.
4- Recirc AMD as a leachant showed the best performance.
5- A pH value of 4 had no negative impact on test performance.
6- A big % of TREE stays within the solid material after leaching.
6-Cerium (Ce), neodymium (Nd), … the most abundant REEs.



…uces more REE.
2… …cy of 0.60% to 0.78%.
3- Inner diffusion is the predominant mechanism that limits the rate at which R… CCR.



Conclusion

It is possible to extract REE from CCR by providing the necessary conditions and factors

THANK YOU

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References

Coint, N., & Dahlgren, S. (2019). Rare earth elements (REE) in two long drill-cores from the Fen Carbonatite Complex, Telemark, Norway (preliminary version).

Google maps

https://www.google.com/maps/place/Loveridge+Coal+Mine/@39.6048189,-80.2868182,759m/data=!3m2!1e3!4b1!4m6!3m5!1s0x883587bdeb6236b3:0x603194de18913992!8m2!3d39.6048189!4d-80.2842433!16s%2Fg%2F1tf7brr2?entry=ttu&g_ep=EgoyMDI1MDMyNC4wIKXMDSoJLDEwMjExNDUzSAFQAw%3D%3D

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