Green Remediation of Acid Mine Drainage Impacted Water: A Field-Scale Filter Development using an Industrial Byproduct

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Outline

- Introduction
- Objectives
- Methods and Results
- Major Findings

What is AMD?

- AMD is a highly acidic and metal-rich solution produced naturally during mining operation.
- Mostly, AMD is produced due to the oxidation of pyrite (FeS_2) in the presence of oxygen and water.

$$FeS_2 + 3.75\ O_2 + 3.5\ H_2O \longrightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+ + heat$$

- Extremely acidic pH (as low as 2-4) and metal toxicity have severe impact on aquatic biodiversity.

Impact of AMD on Ecosystem

- Once exposed to AMD, the quality of adjacent surface water degrades drastically and eventually becomes unsuitable for sustaining biodiversity.
- Additionally, soils exposed to AMD become structurally unstable and highly prone to erosion.

AMD's Impact on Environment

Pic Reference: earthmagazine.org

Objective

The main objective of this study was to develop and optimize a novel, cost-effective, efficient and "green" technology for the remediation of acid mine drainage (AMD)-impacted water.

Study site: Tab-Simco mine

- The Tab-Simco site is an abandoned coal mine located 6 miles southeast of Carbondale, Illinois.
- This area underwent underground coal mining (1890-1955) and surface coal mining (1960's and 1970's).
- The area currently contains 40,000 to 77,000 m^3 of severely contaminated mine pool (Smith, 2002).
- In 1996, the Tab-Simco site was reported as one of the highly contaminated AMD sites in the mid-continent region.
- Currently, an average of 150m^3 AMD is being generated per day.

Study site: Tab-Simco mine

- AMD deposition has created a 7 acre "Kill-zone".
- 2 miles of adjacent Sycamore Creek is also heavily impacted by AMD-pollution.
- In 2007, a sulfate reducing bioreactor (SRB) was constructed in the Tab-Simco site, but the system failed in 2011. The bioreactor is currently filled with AMD water.

Google Earth image of the Tab-Simco site (Taken on 10-14-14)

Water Treatment Residuals and “green” remediation of AMD

- Drinking water treatment residuals (WTRs) are by products of drinking water treatment process. Depending on the type of flocculating or coagulating agent (alum, iron salt or lime) the Al-WTR, Fe-WTR or Ca-WTR is produced.

- More than 2 mega tons of WTRs are generated from the water treatment facilities in the US every day.

- Al and Fe WTRs are primarily composed of amorphous aluminum and iron oxides and hydroxides which provide the reaction sites for the adsorption of different heavy metals like Cu, Pb and Zn.

Types of WTRs

Al-WTR- City of Carbondale water treatment plant, IL.

Ca-WTR- Saline Valley water treatment plant, IL.

Characterization of WTRs

Sample	pH	EC (µS/cm)	OM (%)	C(%)	N(%)	Total		Oxalate	
						Al	Fe	Al	Fe
						----------mg/kg----------			
Al-WTR	5.9 ±0.06	1615 ±10.2	6.78 ±0.21	21.3 ±0.83	0.97 ±0.02	35691 ±114	15.1 ±1.7	28552 ±93	6.8 ±0.3
Ca-WTR	9.4 ±0.3	1552 ±2.7	0.49 ±0.01	10.4 ±0.41	0.61 ±0.05	191 ±2.5	1200 ±8.3	89 ±5.2	540 ±9.1

Why WTRs?

- Cost effective
- Sink of metals and organics
- **Non hazardous material (TCLP test)**
- Safely land-applied

Toxicity Characteristic Leaching Protocol (TCLP) –RCRA 8, Al, & Fe

	As	Ba	Cd	Cr	Pb	Hg	Se	Ag	Al	Fe
	-- mg/L --									
Al-WTR	<MDL	0.07	0.006	0.07	0.06	<MDL	<MDL	<MDL	166	1.8
Ca-WTR	0.005	<MDL	0.002	0.09	<MDL	<MDL	<MDL	<MDL	1.03	16.6
EPA Limit	5.0	100	1.0	5.0	5.0	0.2	1.0	5.0	NR	NR

<MDL= Below Method Detection Level
NR= Not Regulated

Characterization of AMD-impacted water collected from Tab-Simco

Currently Non-functional SRB Pond

Sycamore Creek

	pH	EC (ms/ cm)	Mineral Acidity (mg/L $CaCO_3$)	Total Acidity (mg/L $CaCO_3$)	Al	As	Cd	Cr	Cu	Fe	Ni	Pb	Zn	SO_4^{2-}
					(mg/L)									
Tab-Simco Water	2.27 ± 0.2	3.9 ± 0.03	467 ± 50	1089 ± 60	80 ± 15	4 ± 0.01	1 ± 0.01	1 ± 0.04	4 ± 0.05	137 ± 5	3 ± 0.25	7 ± 1.2	11 ± 0.9	2481 ± 50

RoyChowdhury et al.,2016, Mine Water and the Environment .

Developing a “Green” Remediation Technology for Acid Mine Drainage (AMD)-impacted Water

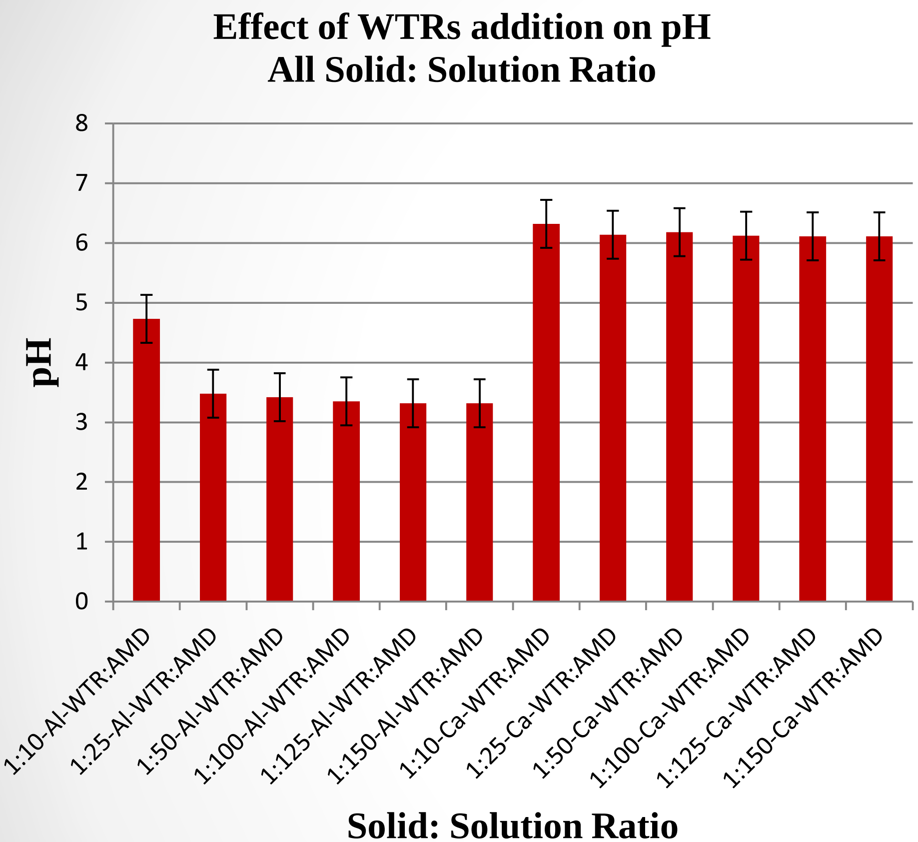
Phase I: Laboratory batch equilibrium study

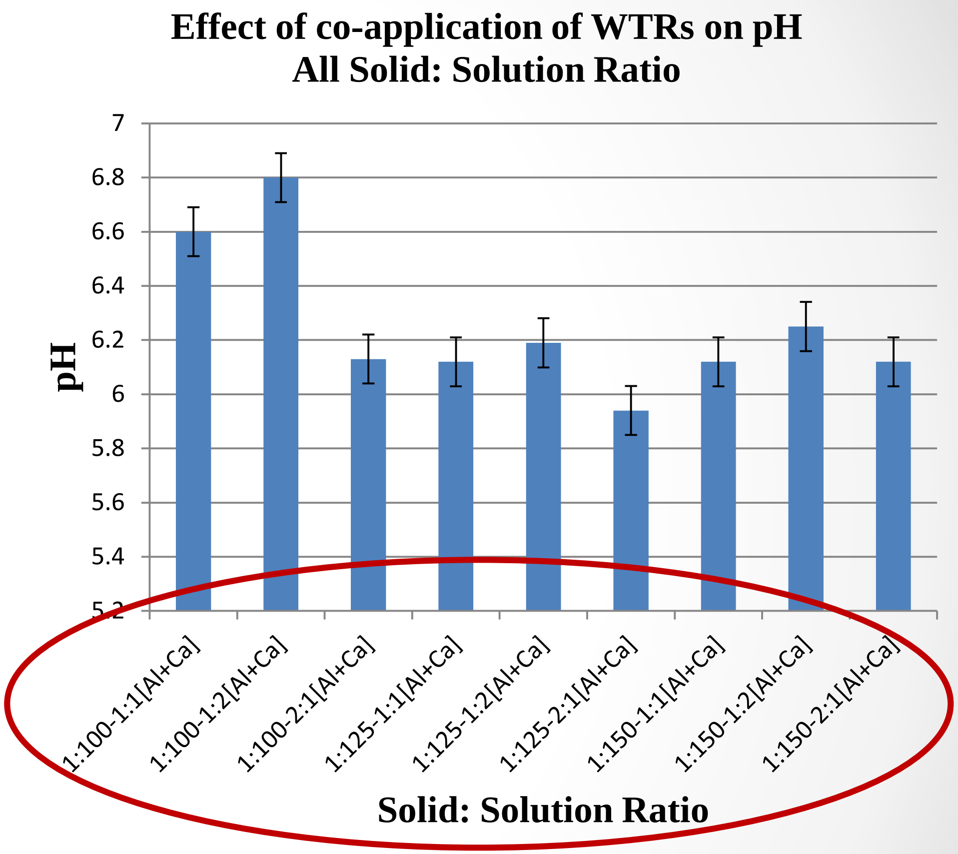
Study of Solid: Solution (WTR:AMD-Water) Ratio

- **Metal adsorption onto Al-WTR**
- **Metal adsorption onto Ca-WTR**
- **Co-application of Al-WTR & Ca-WTR**

- ❑ **Solid: Solution Ratio: 1:10, 1:25, 1:50, 1:100, 1:125 & 1:150**
- ❑ **Co-application of Al-& Ca-WTR at a ratio of 1:1,1:2 & 2:1 respectively**
- ❑ **Contact Time: 24 hr.**

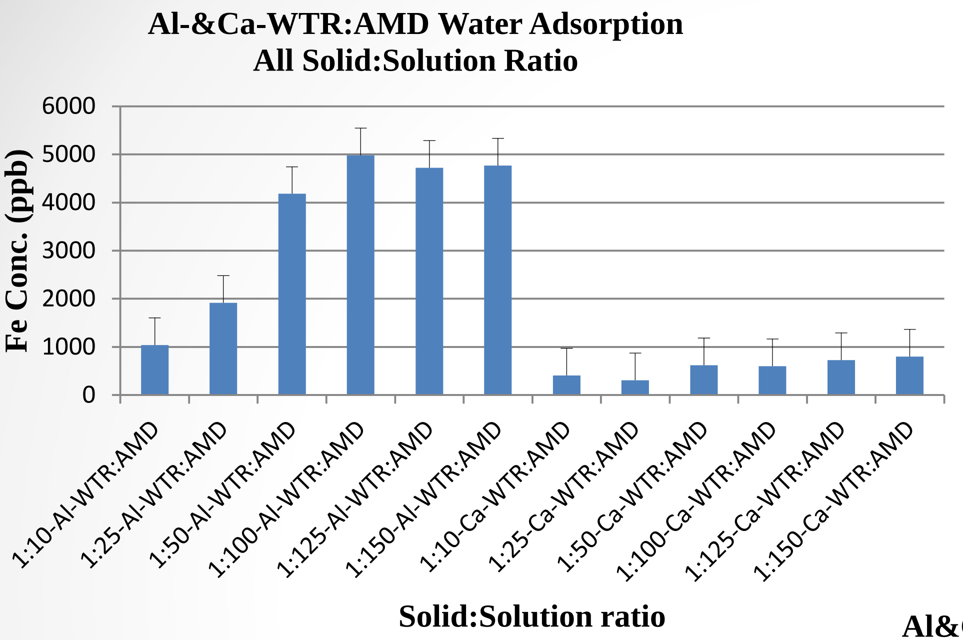
Effect of Solid: Solution ratio on pH of AMD water



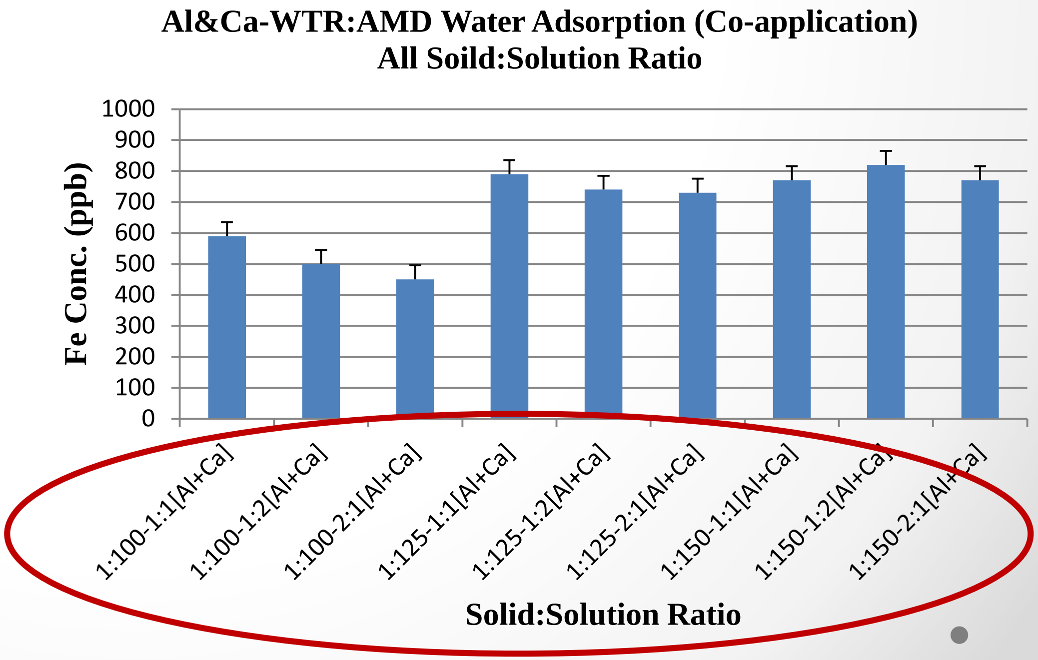


Co-application improved the pH for higher solid: solution ratios

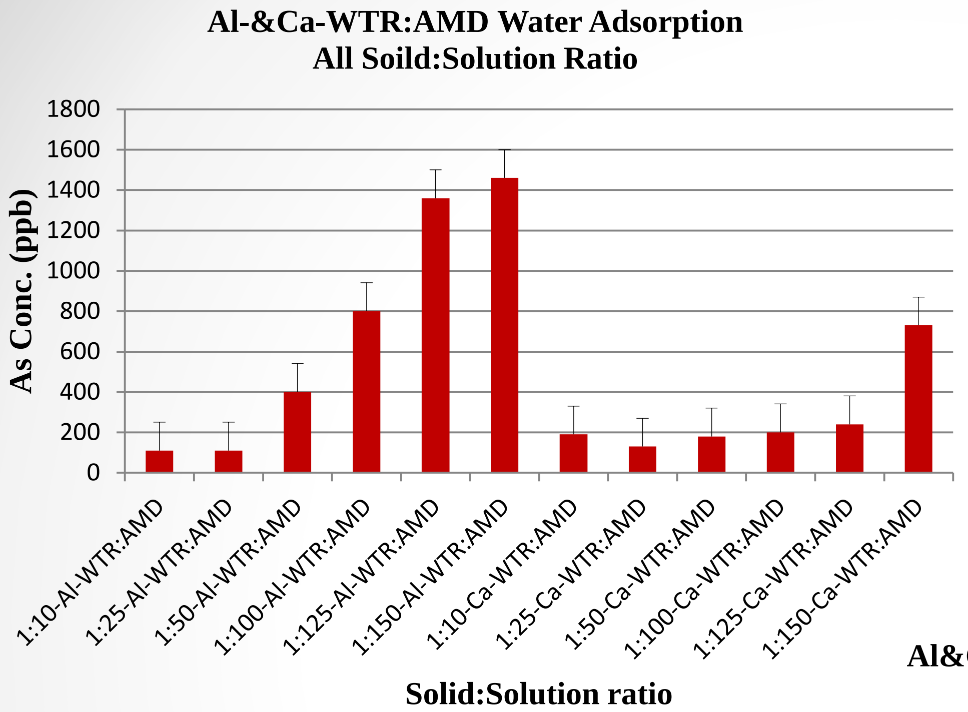
Effect of Solid: Solution ratio on Fe-adsorption



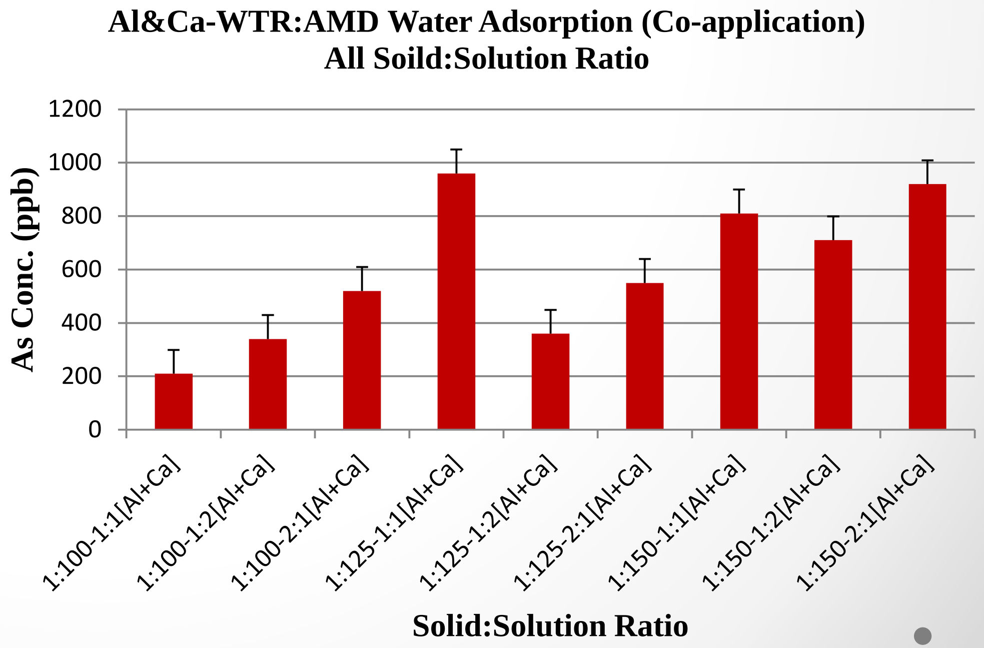
Co-application improved Fe-adsorption for higher solid: solution ratios



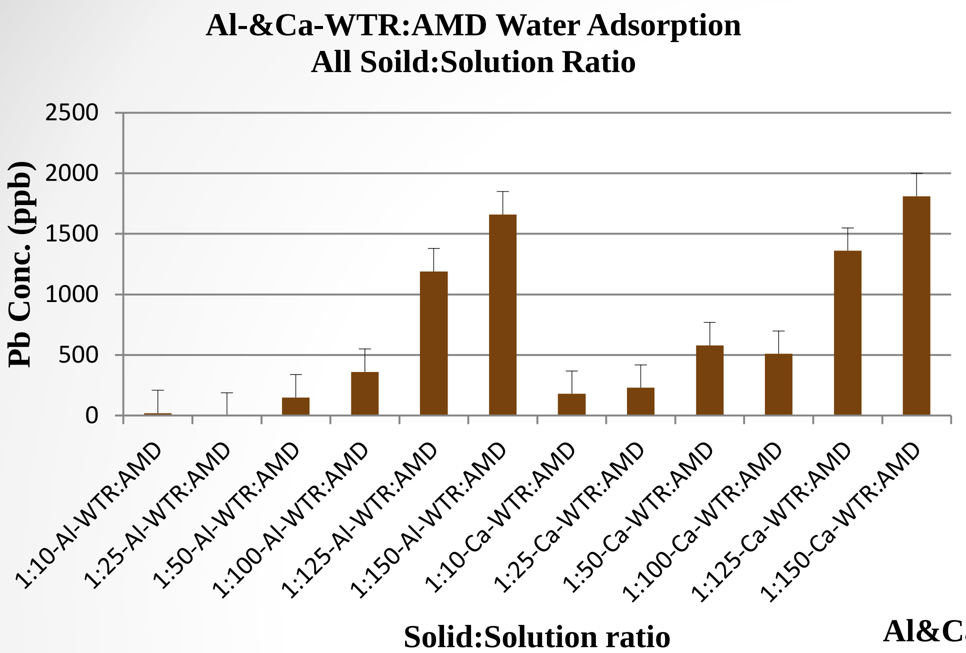
Effect of Solid: Solution ratio on As-adsorption



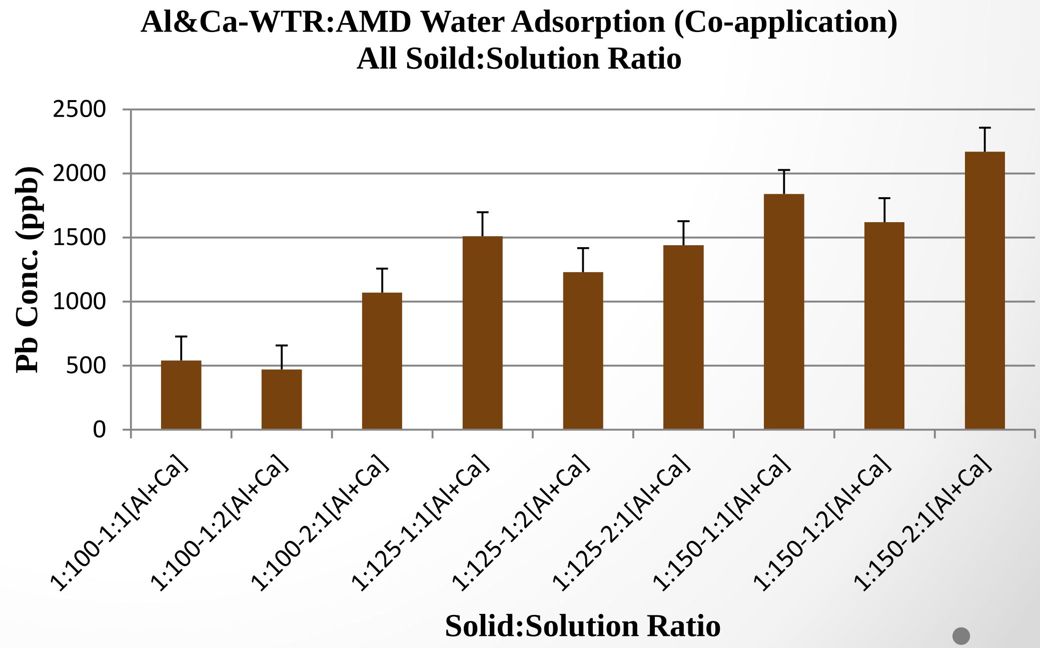
Co-application improved As-adsorption for higher solid: solution ratios



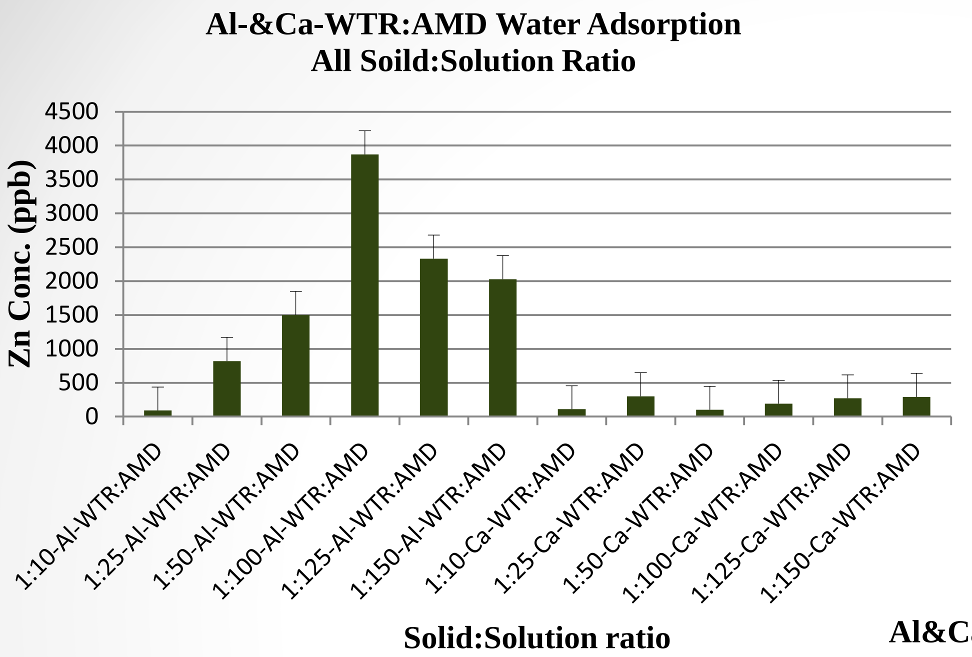
Effect of Solid: Solution ratio on Pb-adsorption



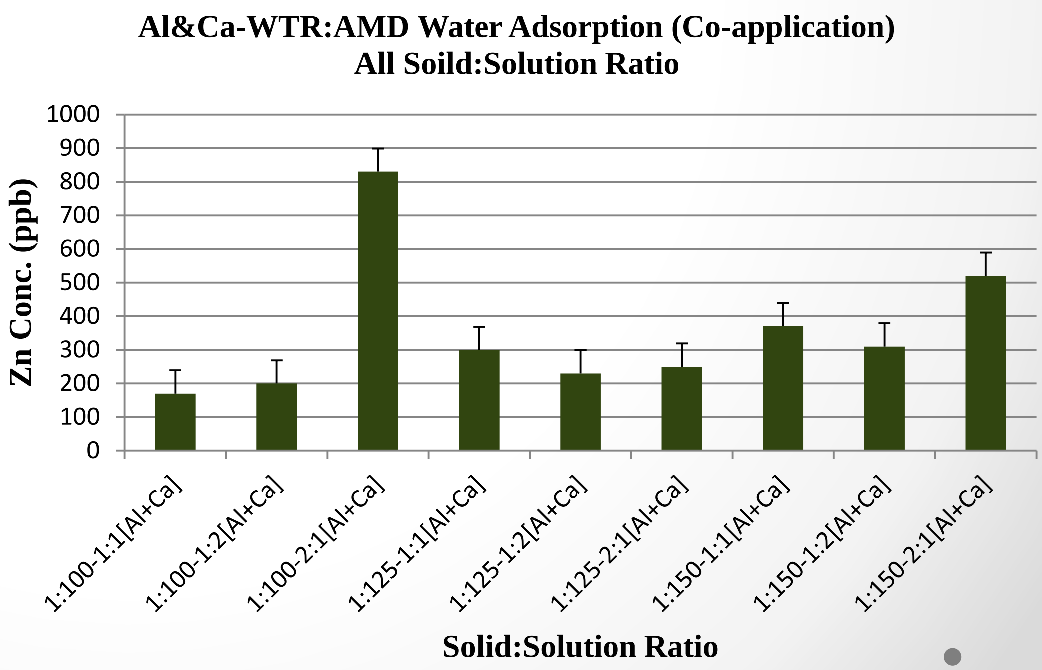
Co-application improved Pb-adsorption for higher solid: solution ratios



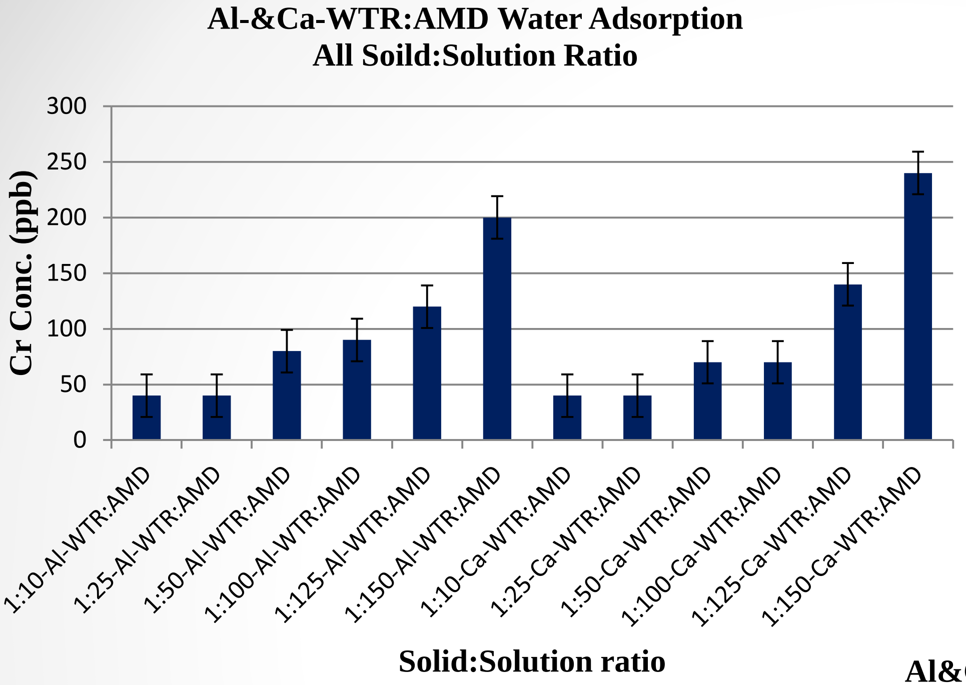
Effect of Solid: Solution ratio on Zn-adsorption



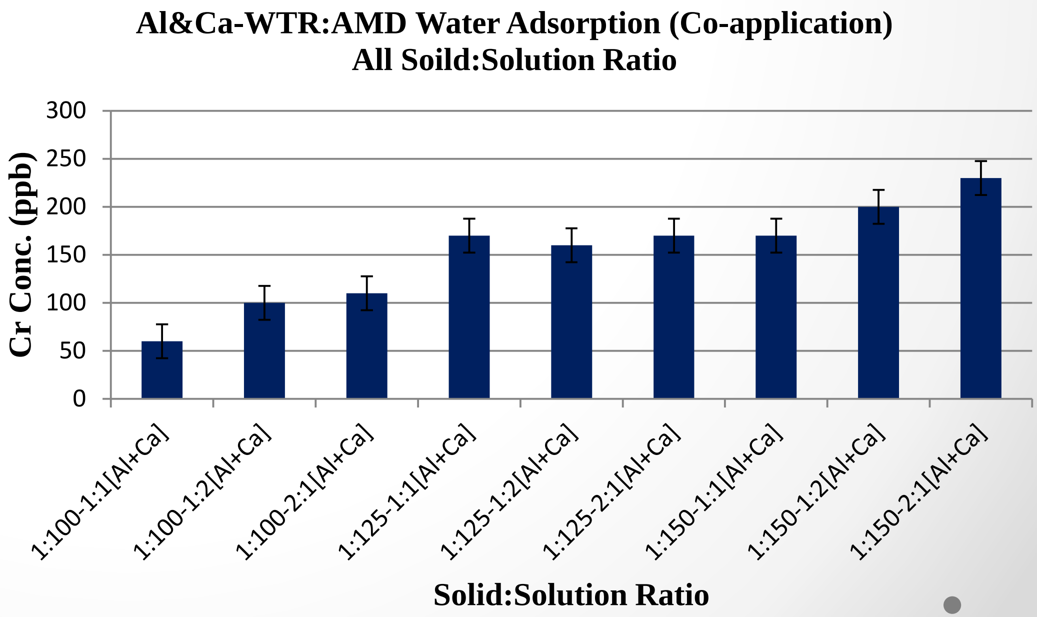
Co-application improved Zn-adsorption for higher solid: solution ratios



Effect of Solid: Solution ratio on Cr-adsorption

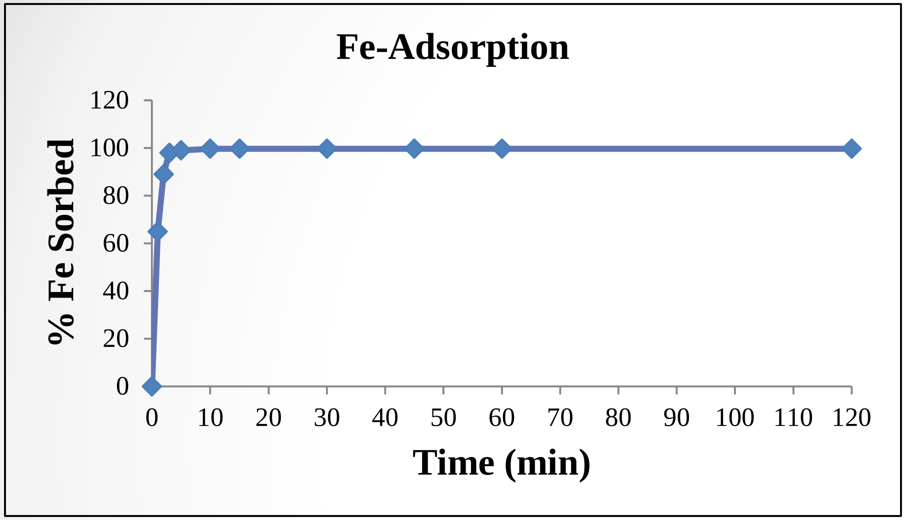


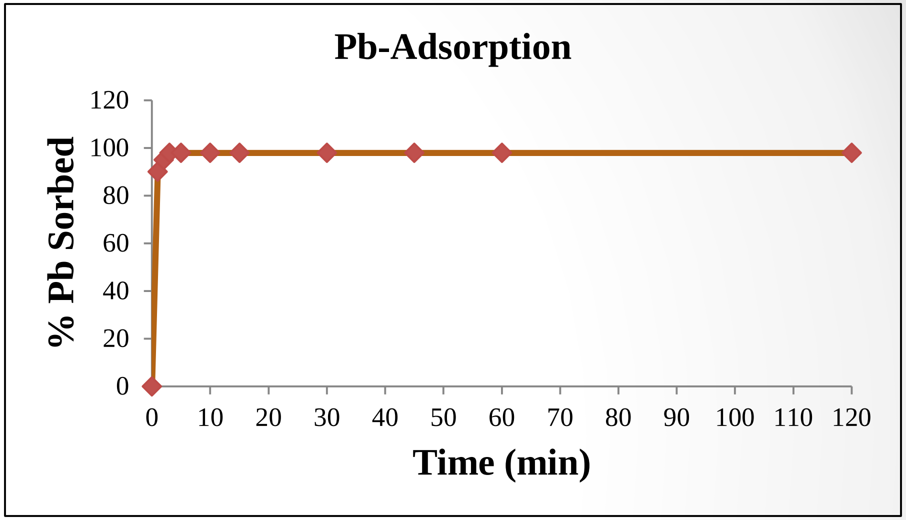
Co-application improved Cr-adsorption for higher solid: solution ratios

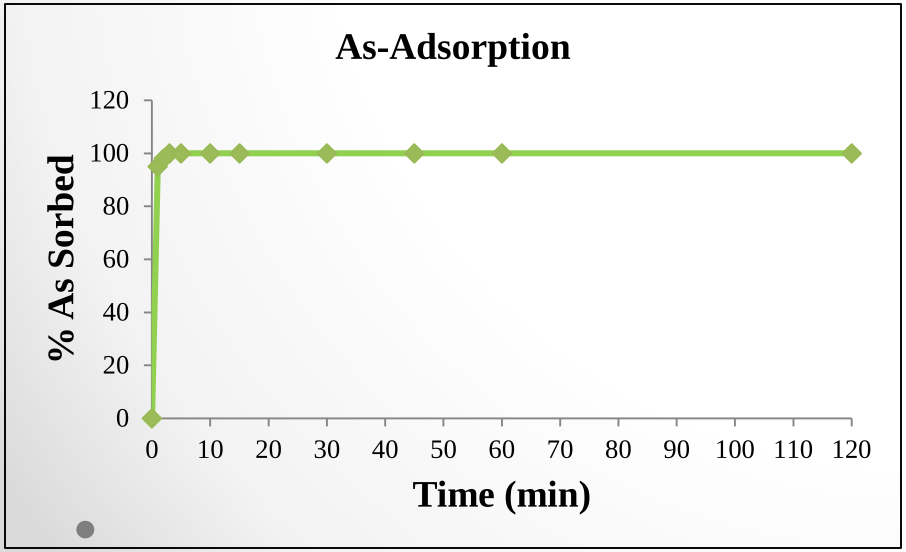


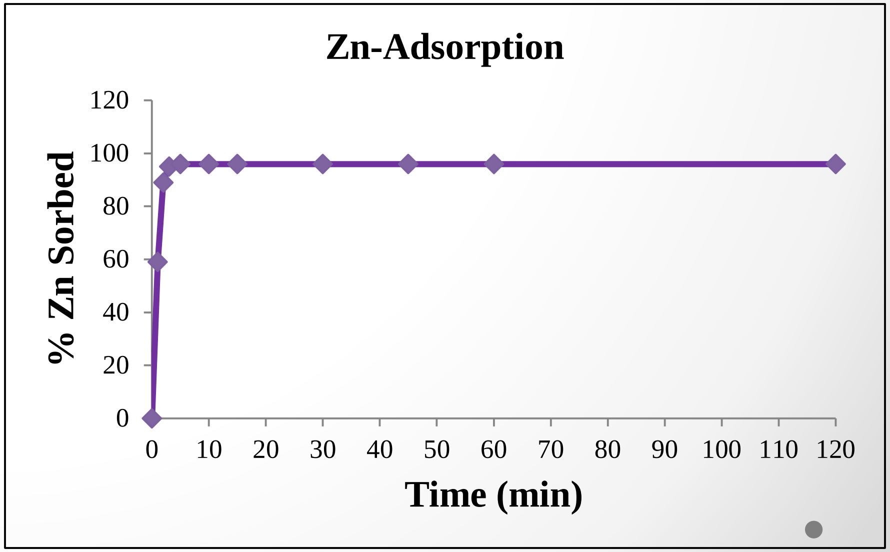
Metal Adsorption

- Solid: Solution Ratio - 1:100
- Co-application- Al-WTR: Ca-WTR – 1:1



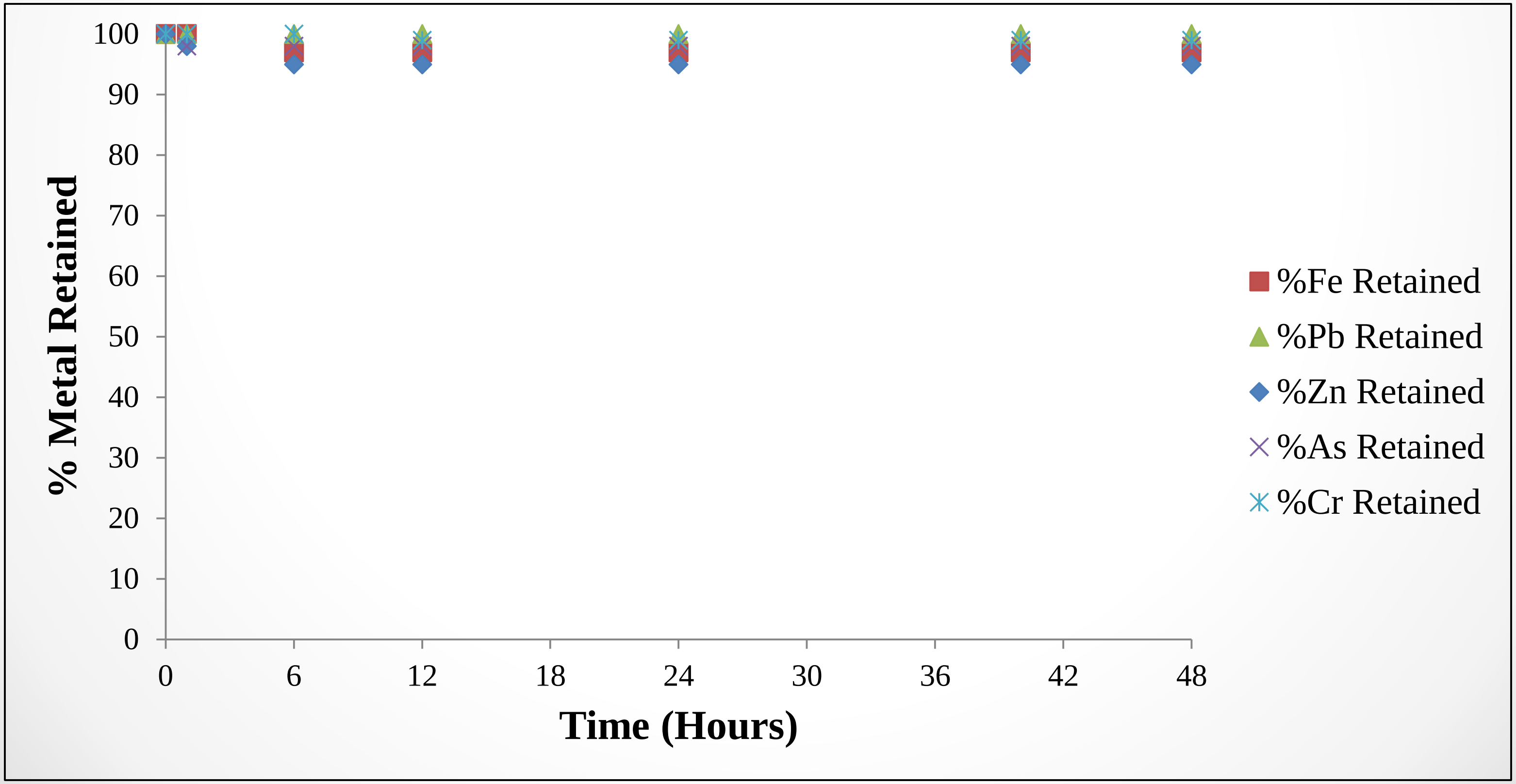






Desorption

- Desorption was carried out for 48 hrs. using DI water
- Solid: Solution Ratio- 1:100



Laboratory Batch Equilibrium Study
What did we learn?

- WTRs were able to significantly remove acidity and metal concentration from AMD water.
- Co-application of Al-WTR and Ca-WTR was able to reduce acidity and metal concentration from AMD water even for higher dilutions.
- Within the first 3 min of adsorption, pseudo-equilibrium was achieved for all metals.
- Desorption study showed that metals were strongly bound on WTR surface and the binding was irreversible.

Developing a “Green” Remediation Technology for Acid Mine Drainage (AMD)-impacted Water

Phase II: Developing a laboratory scale WTR filter bed column for remediation of AMD-impacted water

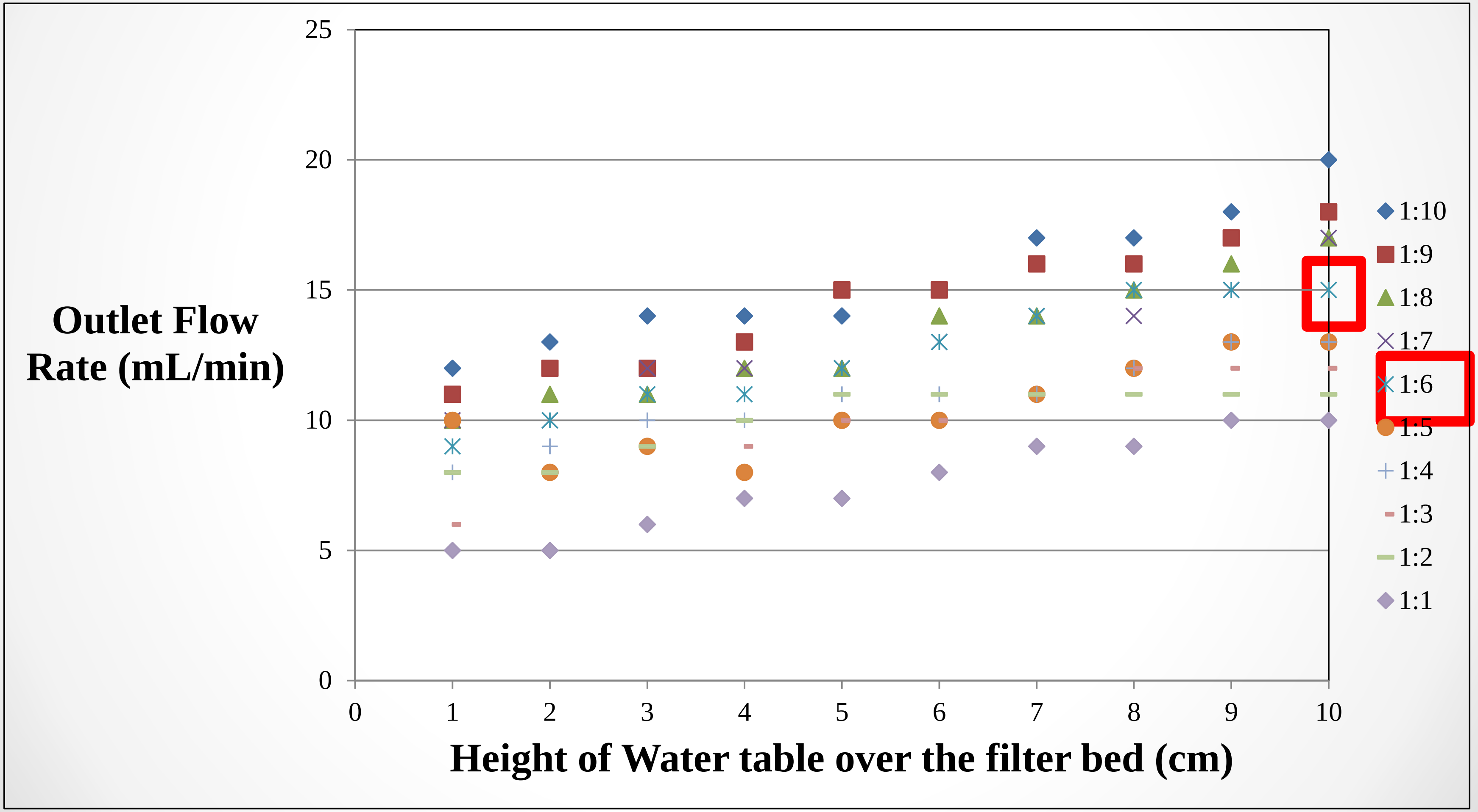
Preparation of WTR Filter-bed Column

- 30 cm × 2.54 cm clear PVC pipe was used.
- To increase filter permeability, WTRs were mixed with sand.
- Ten WTR: Sand ratio were tested to optimize best hydraulic condition- 1:1, 1:2, 1:3, 1:4, 1:5, 1:6, 1:7, 1:8, 1:9, & 1:10.
- Series of hydraulic tests were performed using distilled water.

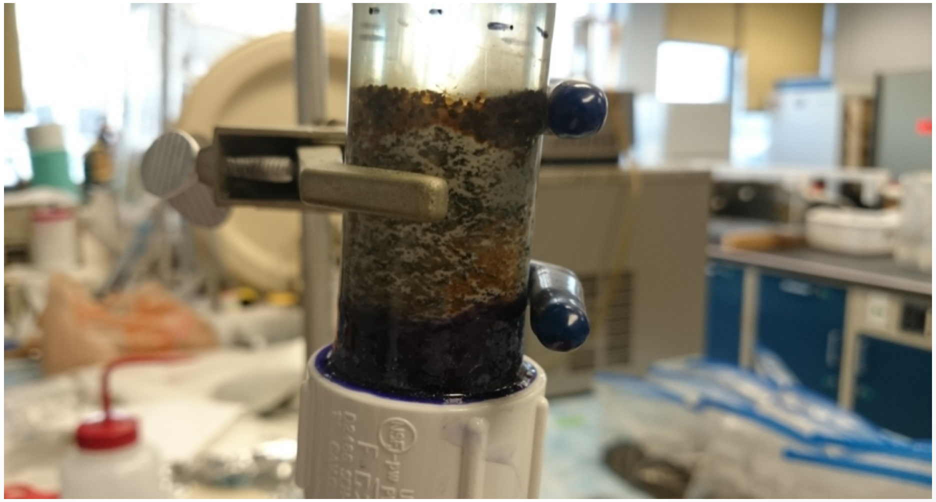
WTR filter-bed column

Hydraulic Test Results

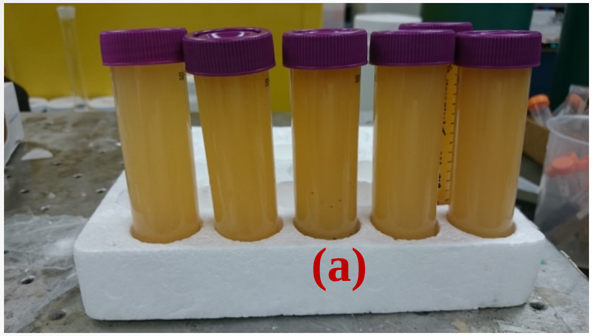
Comparison of Flow Rates of All Ten Columns

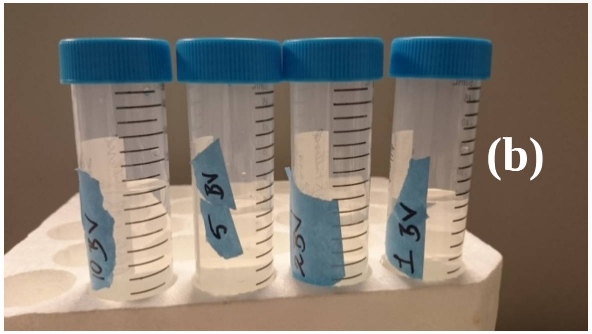


- **1:6 WTR to sand ratio** was selected to ensure an acceptable hydraulic condition.
- **1:1 ratio of Al- WTR and Ca-WTR** was used in this study.
- Volume of the filter-bed was 53 mL.
- AMD was channeled through the filter at a rate of 15mL/min.
- Effluents were periodically collected at different bed volumes up to 24hrs.

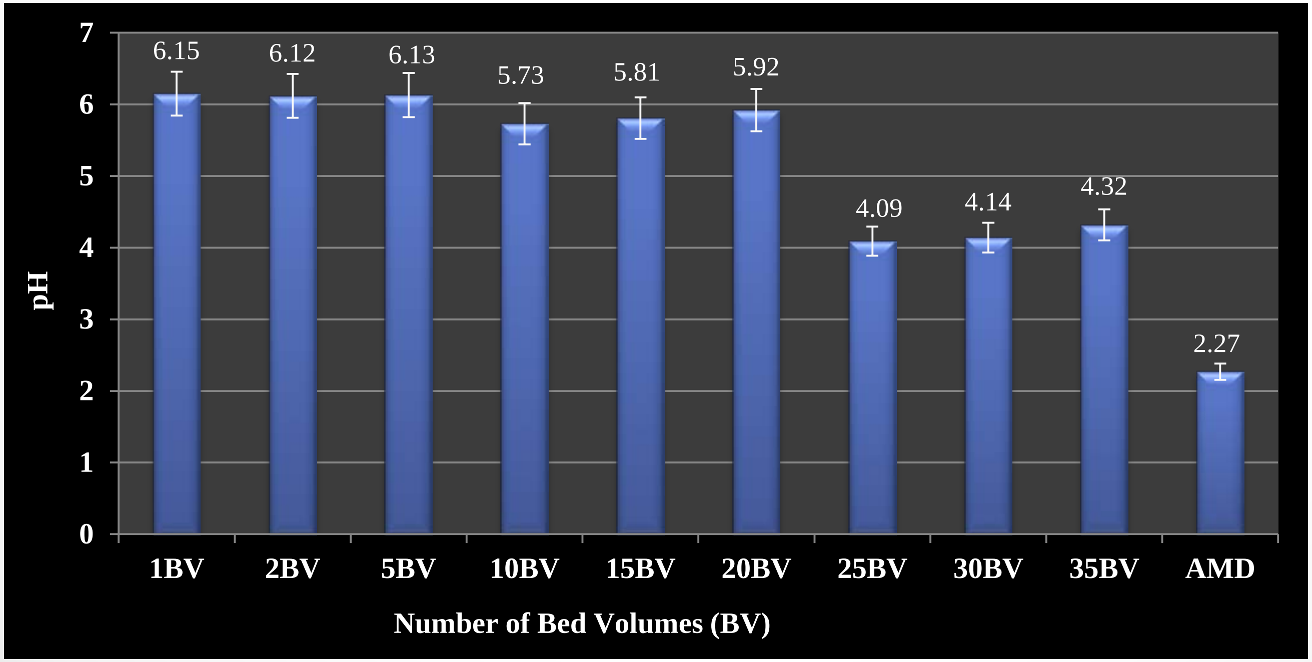


Rust trapped inside the WTR-filter bed during treatment

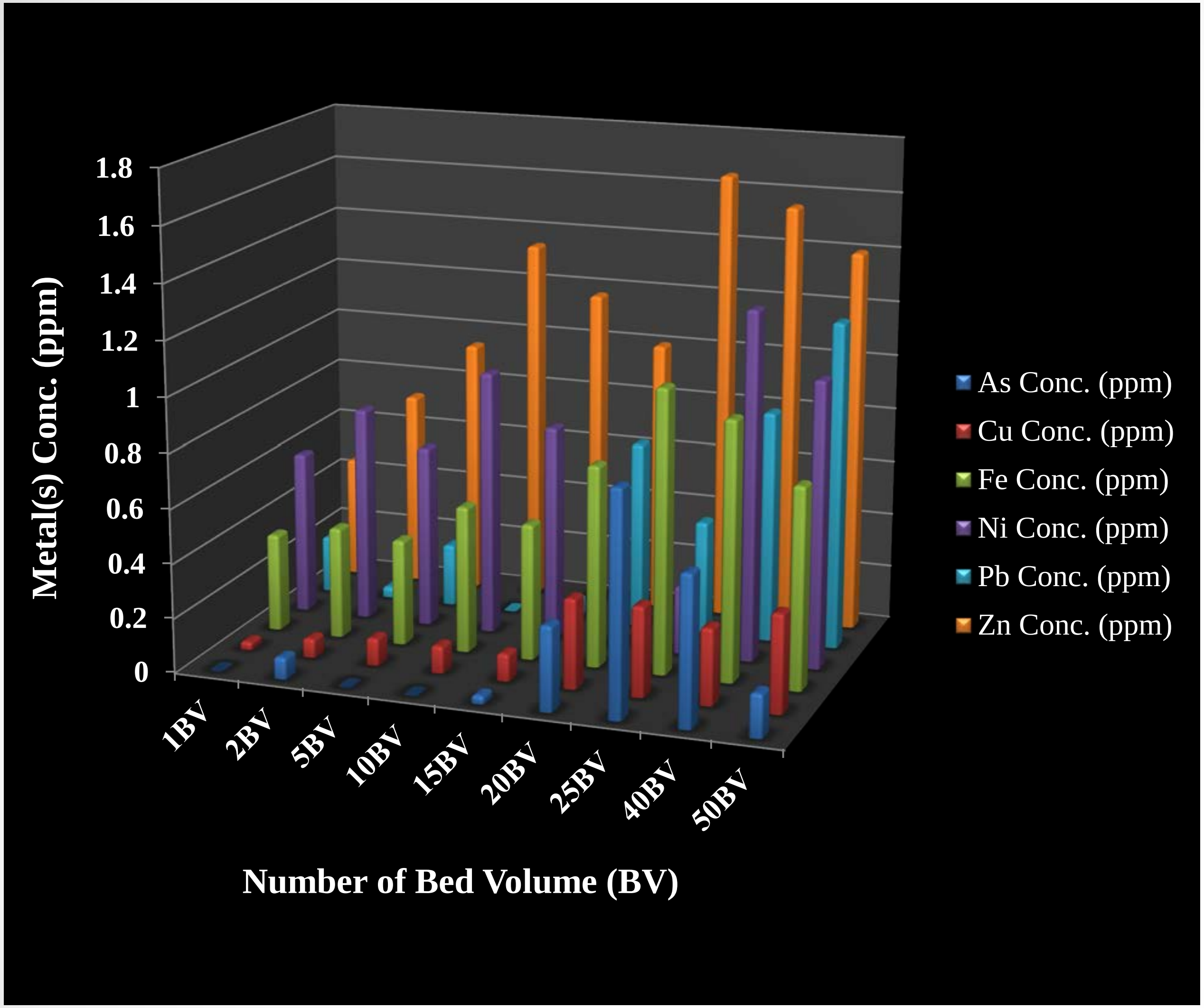




Comparison of raw and WTR treated AMD water (a) before; and (b) after.



Change of pH with different bed volumes.



Max metals removal achieved during the entire test

Metals	Max. Metal Removal% Achieved
As	100
Cu	99.3
Fe	99.7
Ni	91.6
Pb	100
Zn	95.9

Summary of the residual metals in the effluent of WTR filter column tests with different bed volumes

Laboratory Scale WTR-filter Column
What did we learn?

- A ratio of 1:6 WTR to sand was providing a desirable hydraulic conditions.
- For up to 20 bed volumes, the filter media significantly removed acidity and metal concentrations.
- A 36% removal of sulfate was also achieved during the study.

Developing a “Green” Remediation Technology for Acid Mine Drainage (AMD)-impacted Water

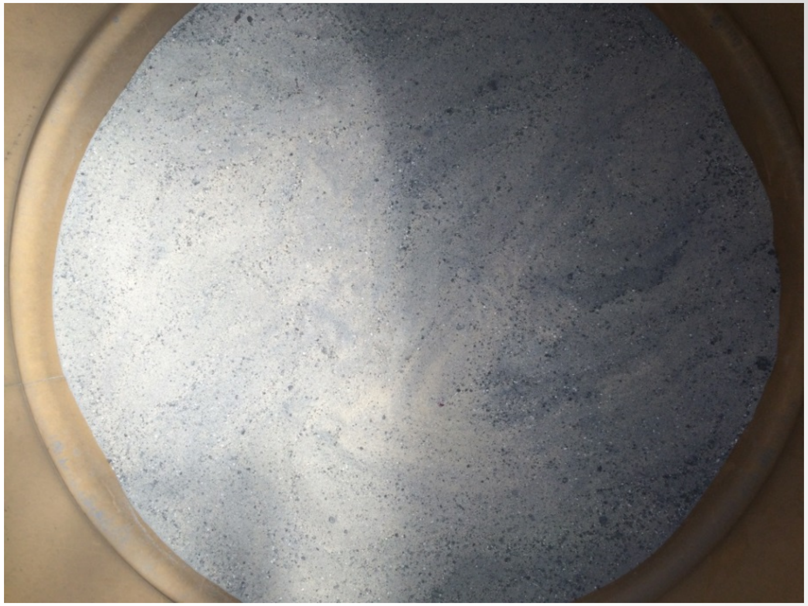
<u>Phase III</u>: Developing a field-scale filter for remediation of AMD-impacted water

- 55 gallon Drum Filter was used for this test.
- Two different types of “green” filter media (1 and 2) were prepared to test the effluent flow rate.

55 gallon Drum Filter

Filter Media 1

- The filter media was prepared by mixing sand and WTRs **1:6 ratio** while keeping **1:1 ratio** of Al-WTR & Ca-WTR.
- The filter media was initially saturated with water and after draining, 100 gallons AMD-water, collected from Tab-Simco SRB pond, was channeled through it.
- Filtered AMD water was collected through the outlet.
- The flow rate was measured ~1 gallon/min.



Filter media inside Filter 1

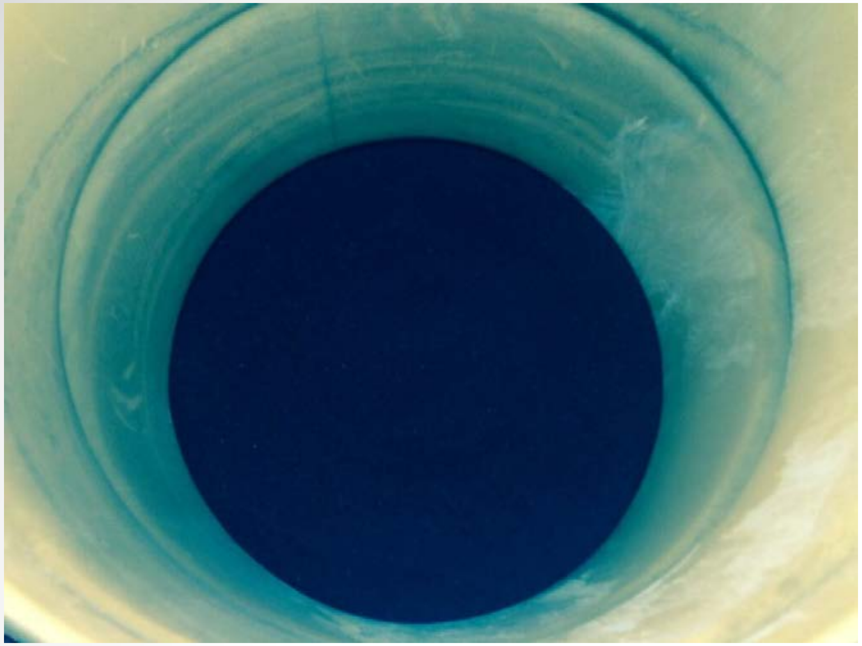
Saturation of filter media with water

AMD water was channeled through filter media

Collection of filtered AMD water

Filter Media 2

- To increase the flow rate of the filter media, some carbon materials were added to sand- WTR mixture.
- A specific amount of carbon material was placed at the bottom of filter 2, and sand-WTR mixture was placed on top of that layer.
- Rest of the process was similar as filter media 1.
- The effluent flow rate for filter media 2 was greater than 4 gallon/min.

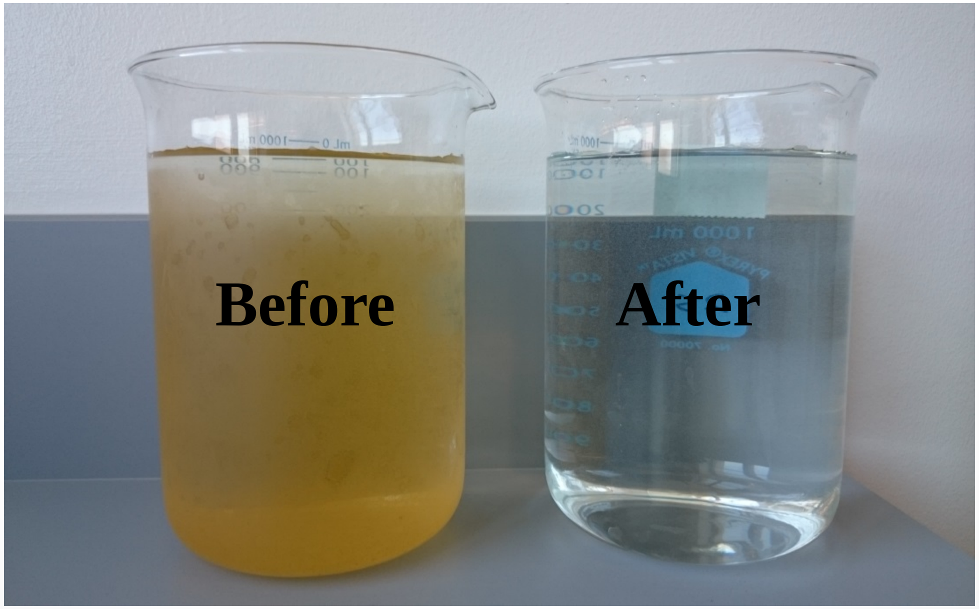


Carbon material at the bottom of the filter

Sand-WTR mixture on top of the carbon layer

Filtered AMD water using Filter Media 2

Visual Comparison of AMD water before and after filtration



Characterization of Tab-Simco AMD Before and After Filtration

Parameter	Raw AMD from Tab-Simco	Filtered AMD Filter Media 1	Filtered AMD Filter Media 2
pH	2.27	7.1	7.8
EC (ms/cm)	3.9	2.3	2.5
Fe (mg/L)	137	0.04	0.06
Al (mg/L)	80	0.5	0.7
Ni (mg/L)	3	0.04	0.04
Zn (mg/L)	11	0.01	0.01
Pb (mg/L)	7	<MDL	<MDL
As (mg/L)	4	<MDL	<MDL
Cr (mg/L)	1	<MDL	<MDL
Cu (mg/L)	4	<MDL	<MDL
SO_4^{2-} (mg/L)	2481	1984	1370

<MDL= Below Method Detection Limit

Field Scale WTR-filter
What did we learn?

- Both the filter media 1 and 2 improved the AMD pH significantly.
- Concentration of metals were found to be well under their USEPA permissible limits in all effluent samples.
- A 44% removal of the initial sulfate concentration was achieved by filter media 2.
- Only difference between the two media was the flow rate. The flow rate of filter media 1 and 2 were 1 gallon/min and 4 gallon/min, respectively.

Major Findings

Our study demonstrated that this **“green”** (recycling of a waste product), **inexpensive** (raw materials obtained free-of-charge), and **ecologically sustainable** (no adverse effect on ecosystem) technology can effectively treat AMD-impacted water.

Acknowledgement

This study was funded by the United States Department of Interior, Office of Surface Mining Reclamation and Enforcement.