Adsorptive Capacity of Orange Peels and Zero Valent Iron Filings

Project Engineers:

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KATHAROS ENGINEERING

1.0 Project Understanding

1.1 Project Purpose

- Continuation of Low-Cost Water Filtration capstone team from previous year
  - Navajo Nation – Problems with uranium (U), arsenic (As), & bacteria contamination in drinking water sources
  - Researched treatment methods - Orange peels for uranium & zero valent iron (ZVI) for arsenic
  - Removal capacity unknown, could not use in filter design

[1] D. Cummings, C. Dilks, Y. Sun, & T. Weir, "Final Design Report: Water Filter for Uranium, Arsenic and Bacteria Removal," Northern Arizona University, Flagstaff, Arizona. May 1st, 2014.

1.0 Project Understanding

1.2 Existing Conditions: Previous Orange Peels & ZVI Testing Results

Contaminant	Treatment Material	USEPA Maximum Contaminant Level (MCL)	Initial Concentration	Percent Removal
Uranium	Orange Peels	30 µg/L	84.71 µg/L	99%
Arsenic	ZVI Filings	10 µg/L	68.65 µg/L	98.8%

[1] D. Cummings, C. Dilks, Y. Sun, & T. Weir, "Final Design Report: Water Filter for Uranium, Arsenic and Bacteria Removal," Northern Arizona University, Flagstaff, Arizona. May 1st, 2014.

1.0 Project Understanding

1.2 Client, Technical Advisor, Stakeholders

- Client – Cheryl Dilks, Engineer I, Brown and Caldwell

- Technical Advisor – Dr. Paul Gremillion, Civil and Environmental Engineering Associate Professor, Northern Arizona University

- Stakeholders – Cheryl Dilks, communities with U and As removal needs, water treatment research community

1.3 Project Description

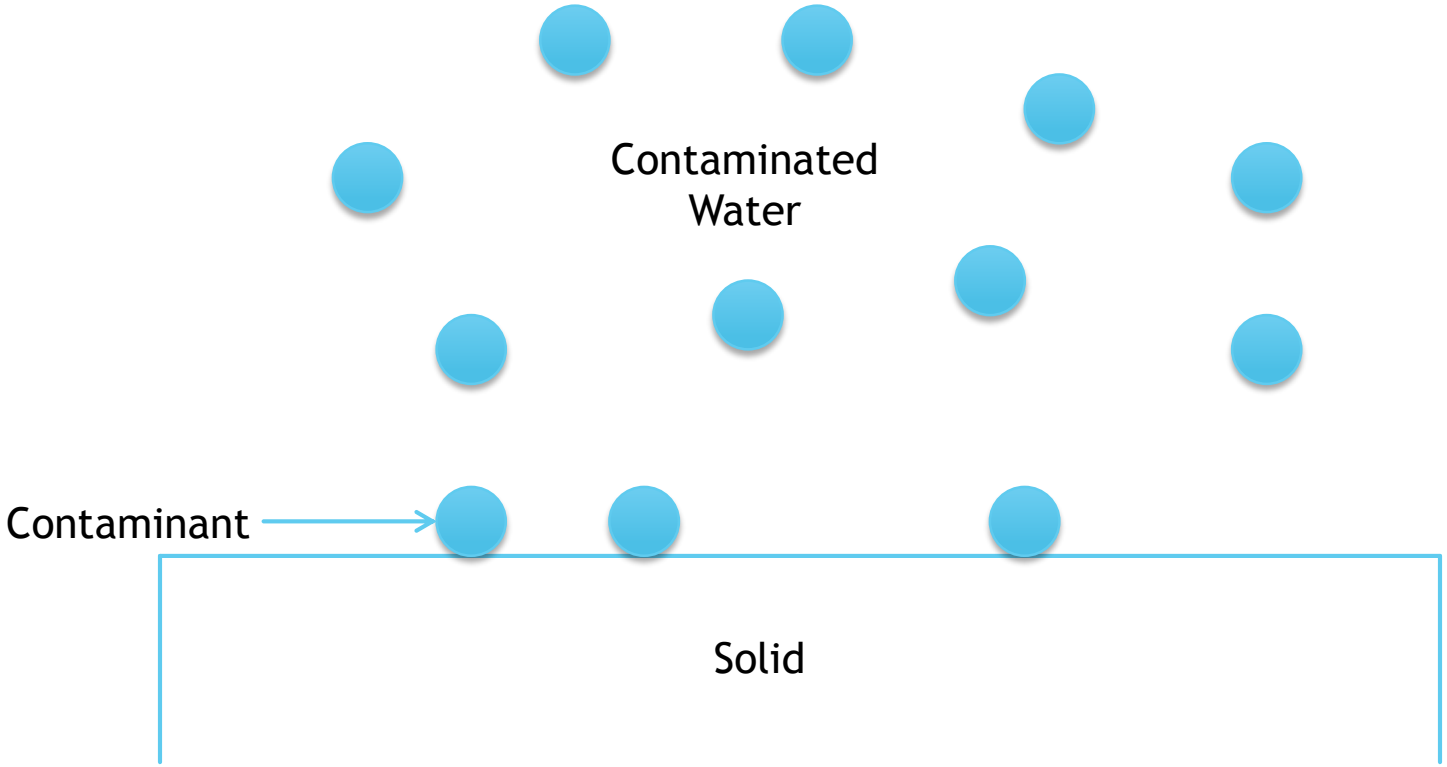
- Design and implement testing plan to determine capacity of orange peels for U removal and ZVI for As removal

1.4 Exclusion

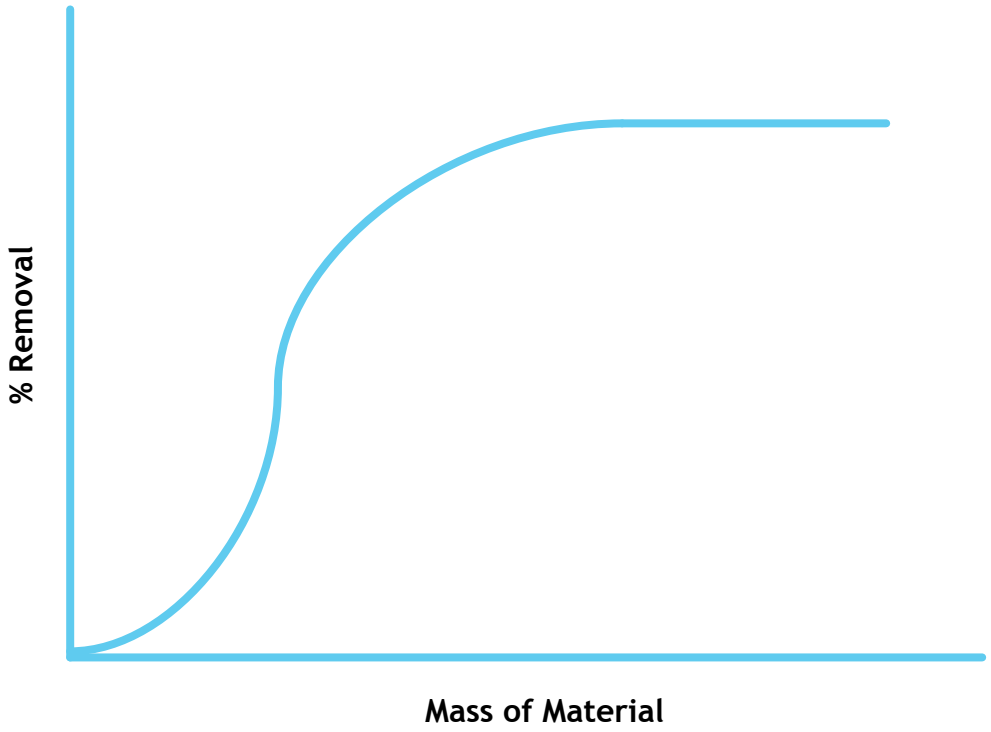
- Kinetics, filter design

2.0 Background Information

2.1 Adsorption Theory



2.0 Background Information



Isotherms

- Use removal data to determine adsorption capacity
- Require broad range of removal data

Challenges

- Determining mass ranges for materials
- Creating synthetic water that models groundwater

2.0 Background Information

Freundlich Isotherm Equation

$$q = K C_e^{1/n}$$

- q = Mass of adsorbate/mass adsorbent (mg/g)
- K = Freundlich isotherm capacity parameter ((mg/g)(L/mg)^(1/n))
- Ce = Equilibrium concentration of adsorbate (mg/L)
- 1/n = Freundlich isotherm intensity parameter (unitless)

Freundlich Isotherm Log Equation

$$\log q = \log K + \frac{1}{n} \log C$$

2.0 Background Information

Langmuir Isotherm Equation

$$q = \frac{Q_0 K_L C_e}{1 + K_L C_e}$$

- q = Mass adsorbate/mass adsorbent (mg/g)
- Q_0 = Maximum adsorption capacity (mg/g)
- K_L = Langmuir isotherm constant (L/mg)
- C_e = Equilibrium concentration of adsorbate (mg/L)

Linear Langmuir Isotherm Equation

$$\frac{1}{q} = \frac{1}{Q_0} + \frac{1}{Q_0 K_L C_e}$$

Langmuir Isotherm Equilibrium Parameter Equation

$$R_L = \frac{1}{1+(1+K_L C_0)}$$

- C_0 = Initial concentration (mg/L)

3.0 Experimental Design

3.1 Experimental Matrix

- Initial U and As concentrations
- Range of mass for orange peel and ZVI filings
- Number of replicates per sample

3.2: Lab Safety Plan

- Safety
- Sample labeling
- Shipping protocols

3.3: Experimental Methods

- Batch testing

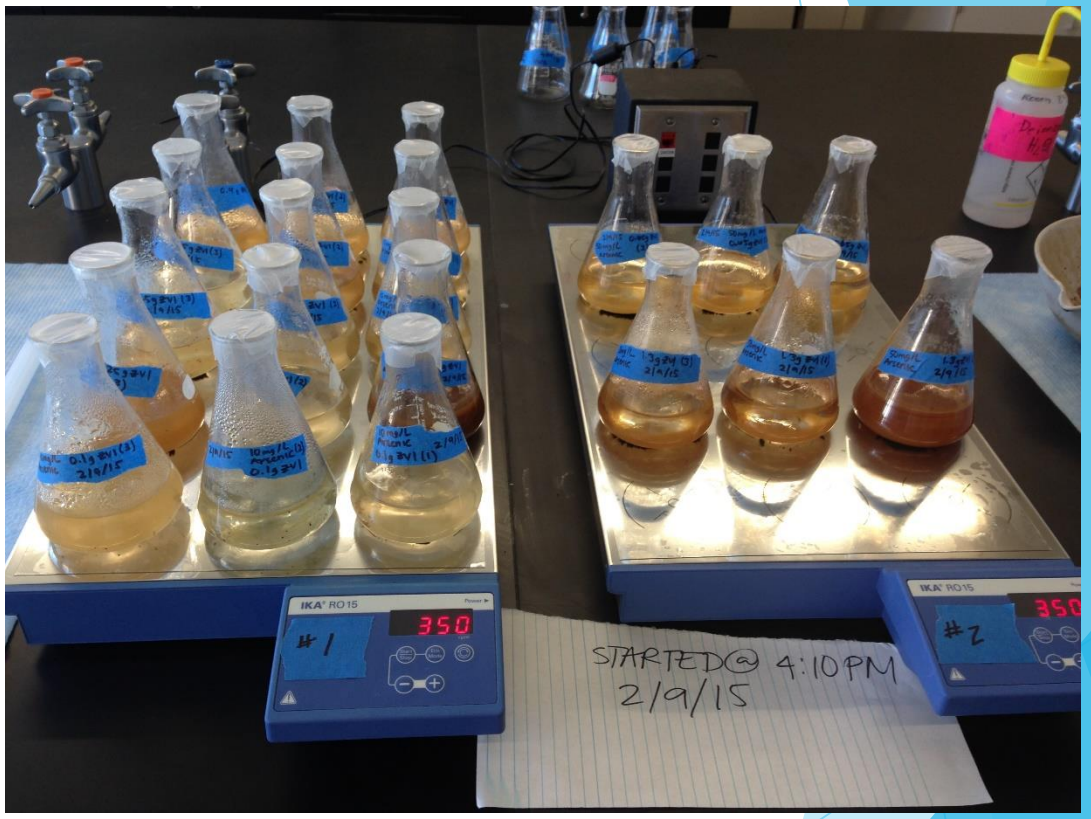


Photo Credit: Makenzi Beltran

4.0 Experimentation

4.1: Material Preparation

Orange Peels

- Cut OP 1cm x 1cm, rinsed in DI water, drying oven (105°C) for 12 hours
- Blender
- Sieve analysis

ZVI Filings

- Soak in DI water for 24 hours

Photo Credit: Makenzi Beltran

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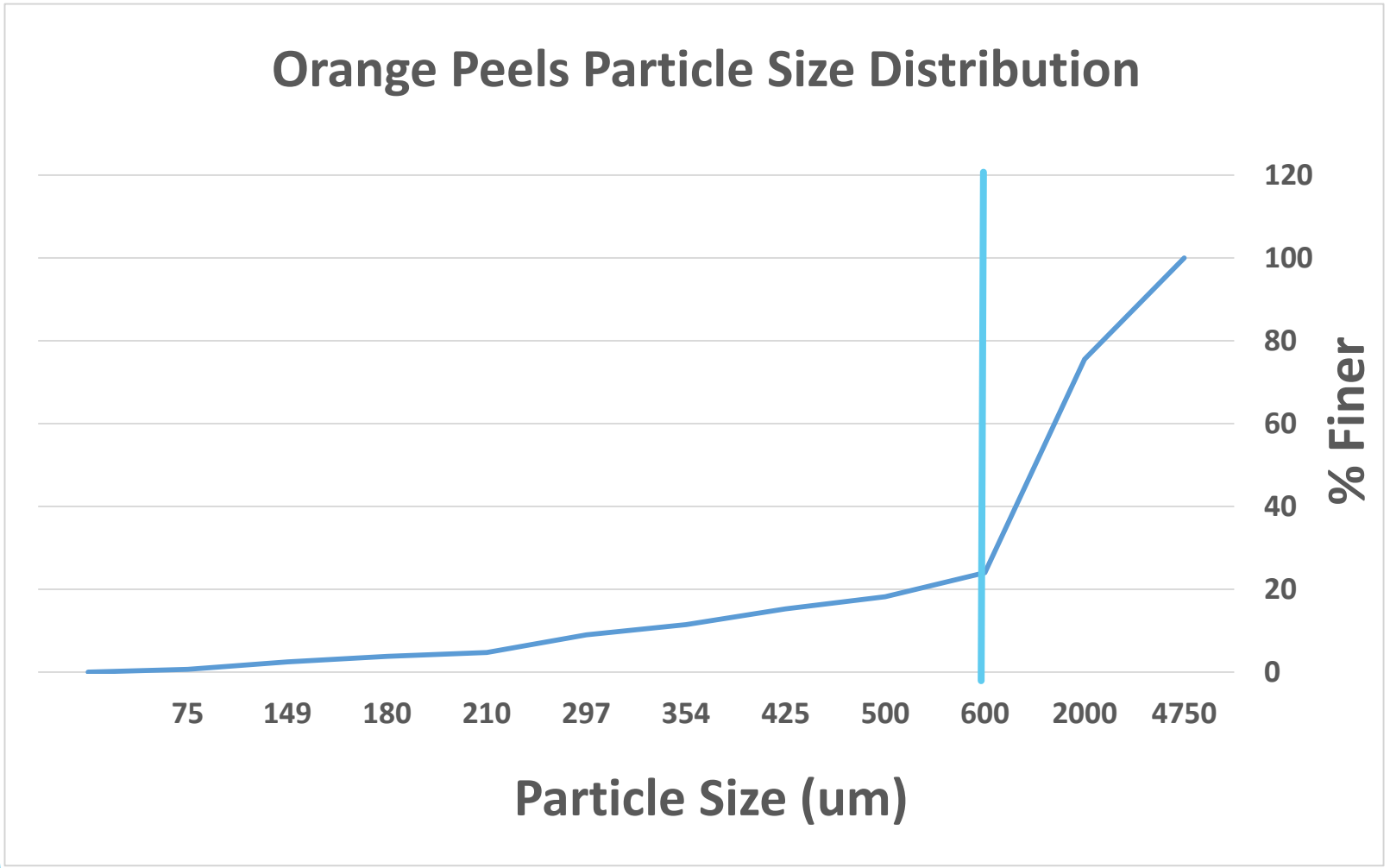
4.0 Experimentation

Particle Size Distribution Analysis

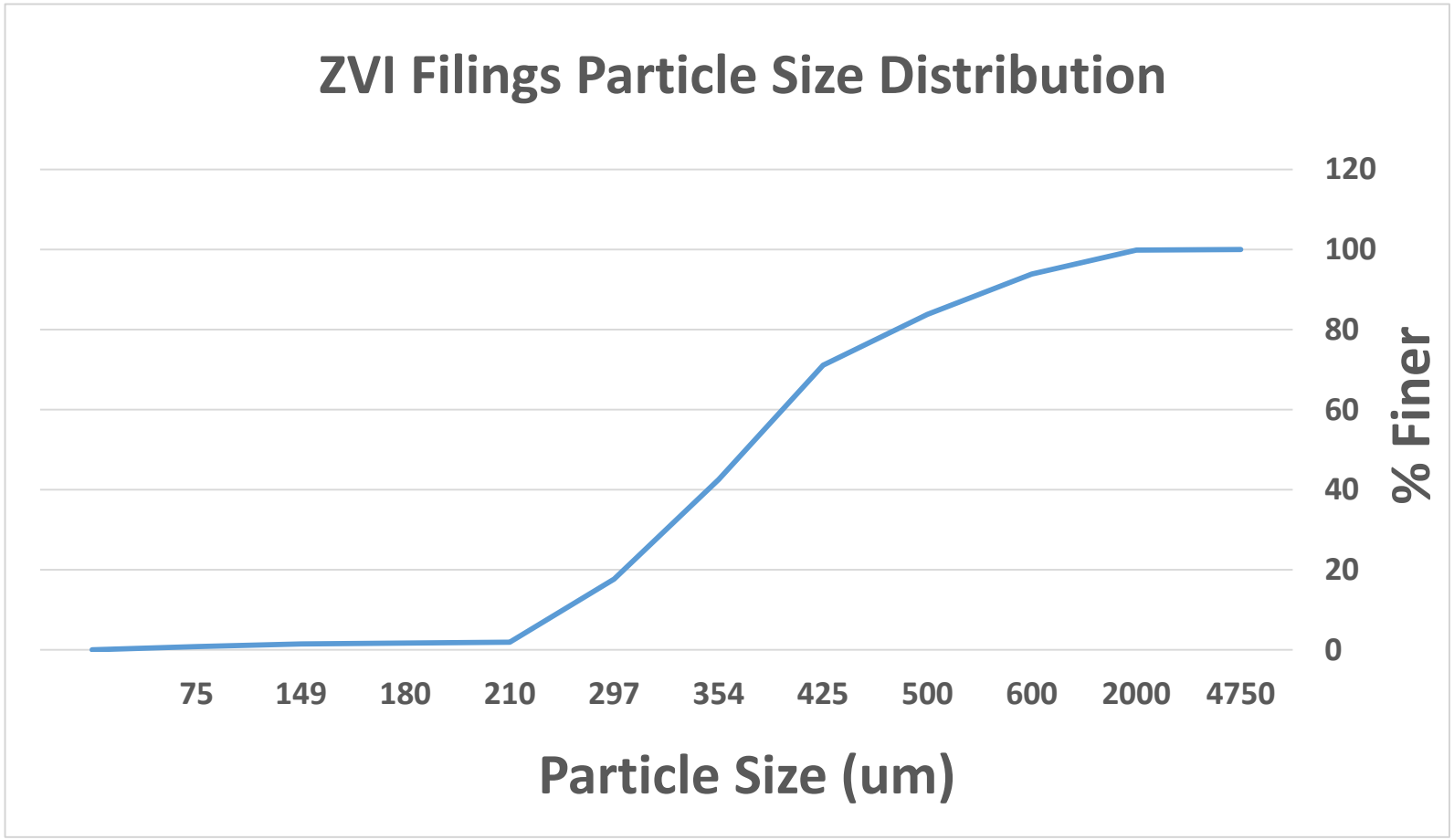
- Orange Peels – only used OP retained on #30 sieve



4.0 Experimentation

Particle Size Distribution Analysis

- ZVI Filings



4.0 Experimentation

4.2 Sample Water Creation & Analysis

- Initial U: 100 mg/L (C1)
- Initial As: 10 mg/L & 50 mg/L (C1)

- pH: 7.52
- Hardness (HACH Method 8226): 286.6 mg CaCO3/L
  - Very hard
- Alkalinity (HACH Method 8221): 26.6 mg CaCO3/L

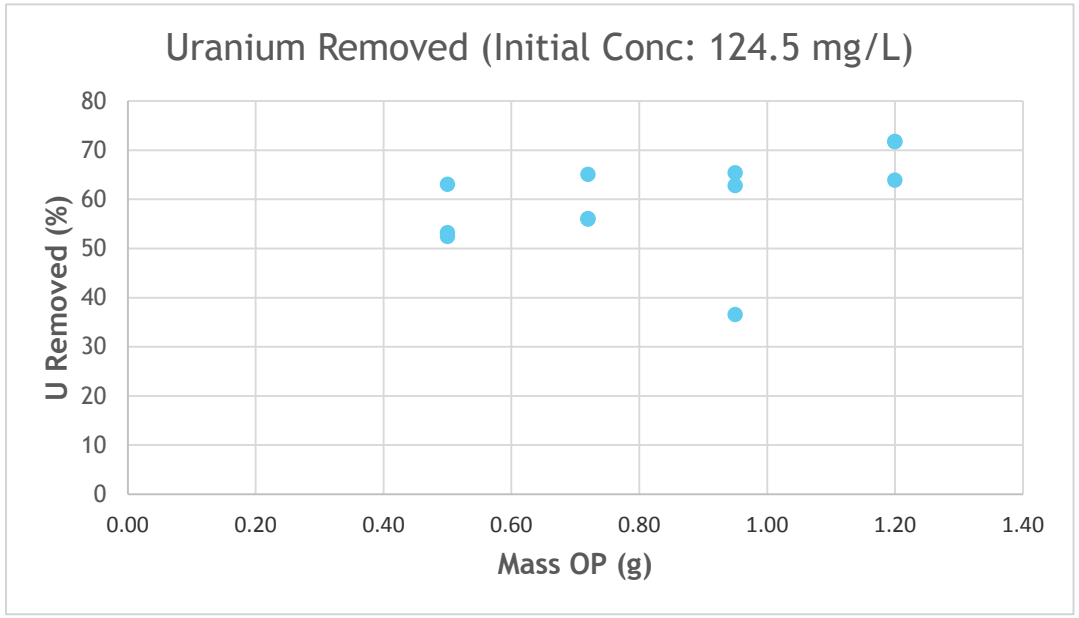
Photo Credit: Makenzi Beltran

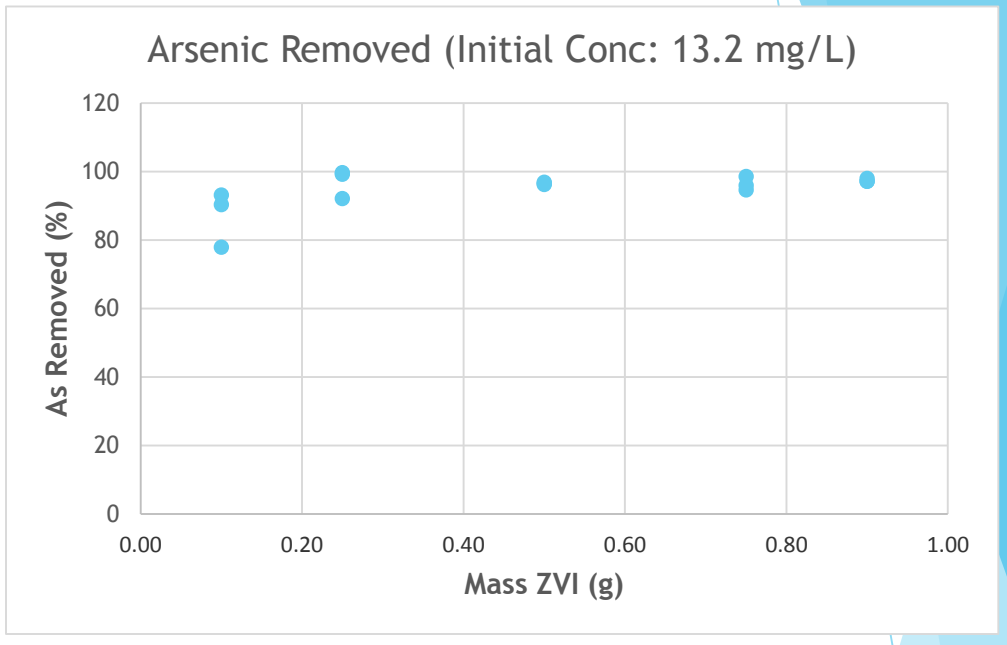
4.0 Experimentation

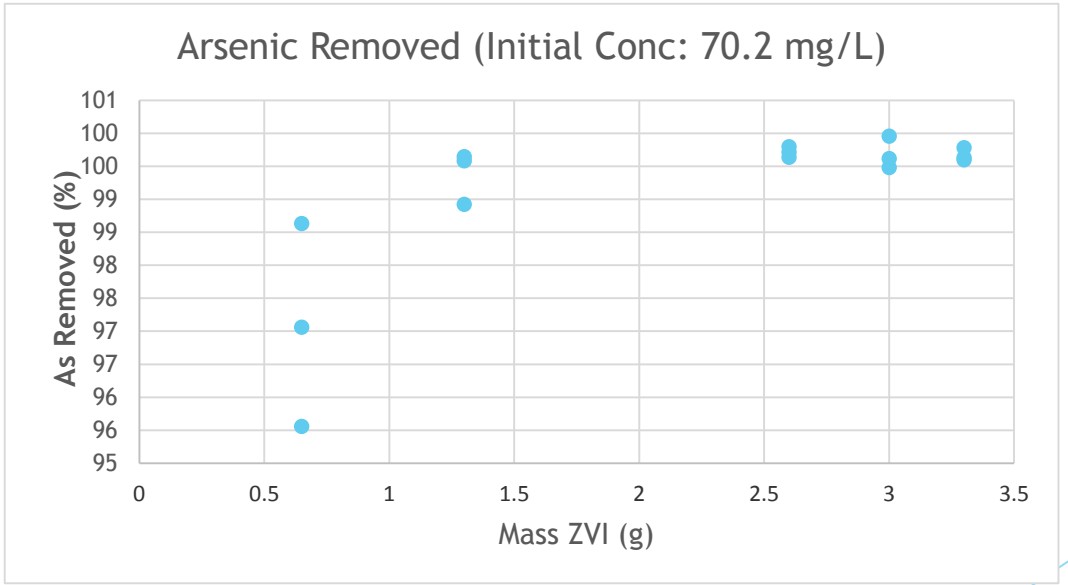
	Constant	Variable
Batch 1		
	OP Size 100 mg U/L	0.5 g OP
		0.72 g OP
		0.95 g OP
		1.2 g OP
	ZVI Size 10 mg As/L	0.1 g ZVI
		0.25 g ZVI
		0.5 g ZVI
		0.75 g ZVI
		0.9 g ZVI
	ZVI Size 50 mg As/L	0.65 g ZVI
		1.3 g ZVI
		2.6 g ZVI
		3 g ZVI
		3.3 g ZVI

- Total Samples = 150
- Northern Arizona University's Statistical Consulting Lab
  - Batch 1: 30% (45)
  - Batch 2: 70% (105)
  - 3 replicates
- Estimated range of removal: 25%-100%

4.0 Experimentation – Batch 1 Results

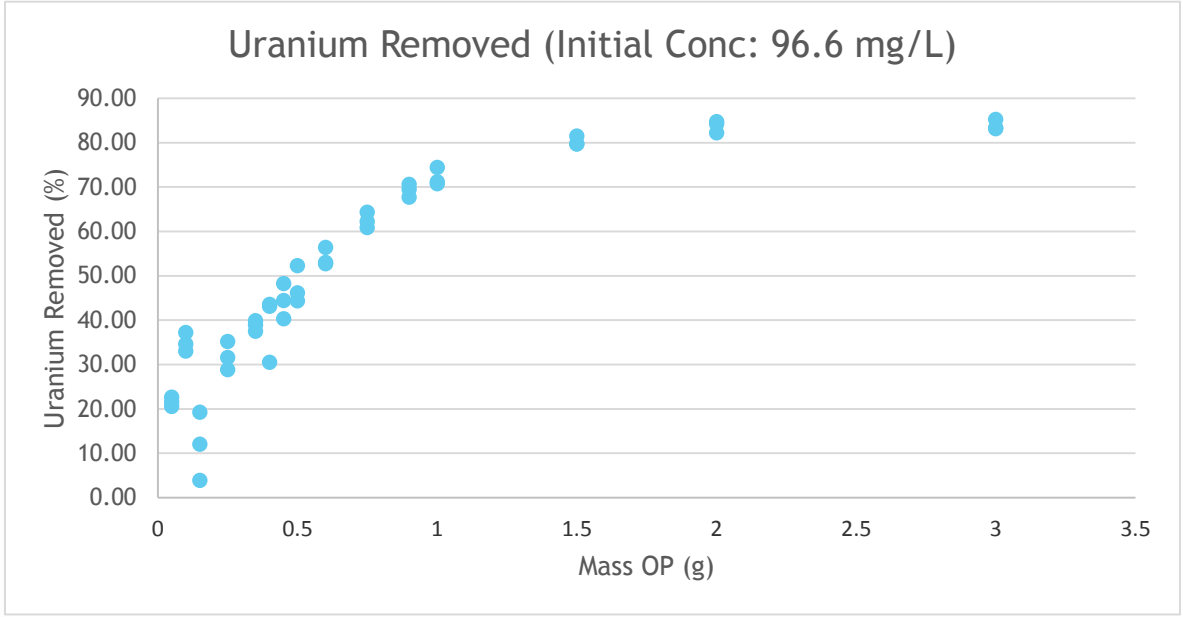


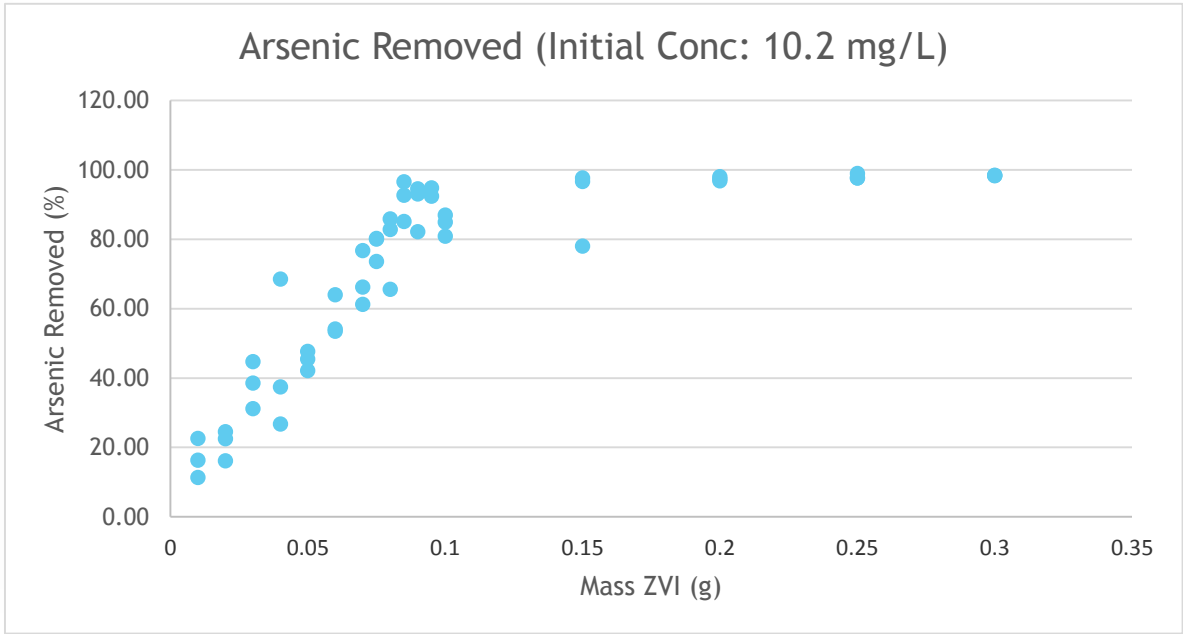




4.0 Experimentation – Batch 2 Results

Batch 2		
	OP Size 100 mg U/L	0.05 g OP
		0.1 g OP
		0.15 g OP
		0.25 g OP
		0.35 g OP
		0.4 g OP
		0.45 g OP
		0.5 g OP
		0.6 g OP
		0.75 g OP
		0.9 g OP
		1 g OP
		1.5 g OP
		2 g OP
		3 g OP
	ZVI Filings 10 mg As/L	0.01 g ZVI
		0.02 g ZVI
		0.03 g ZVI
		0.04 g ZVI
		0.05 g ZVI
		0.06 g ZVI
		0.07 g ZVI
		0.075 g ZVI
		0.08 g ZVI
		0.085 g ZVI
		0.09 g ZVI
		0.095 g ZVI
		0.1 g ZVI
		0.15 g ZVI
		0.2 g ZVI
		0.25 g ZVI
		0.3 g ZVI

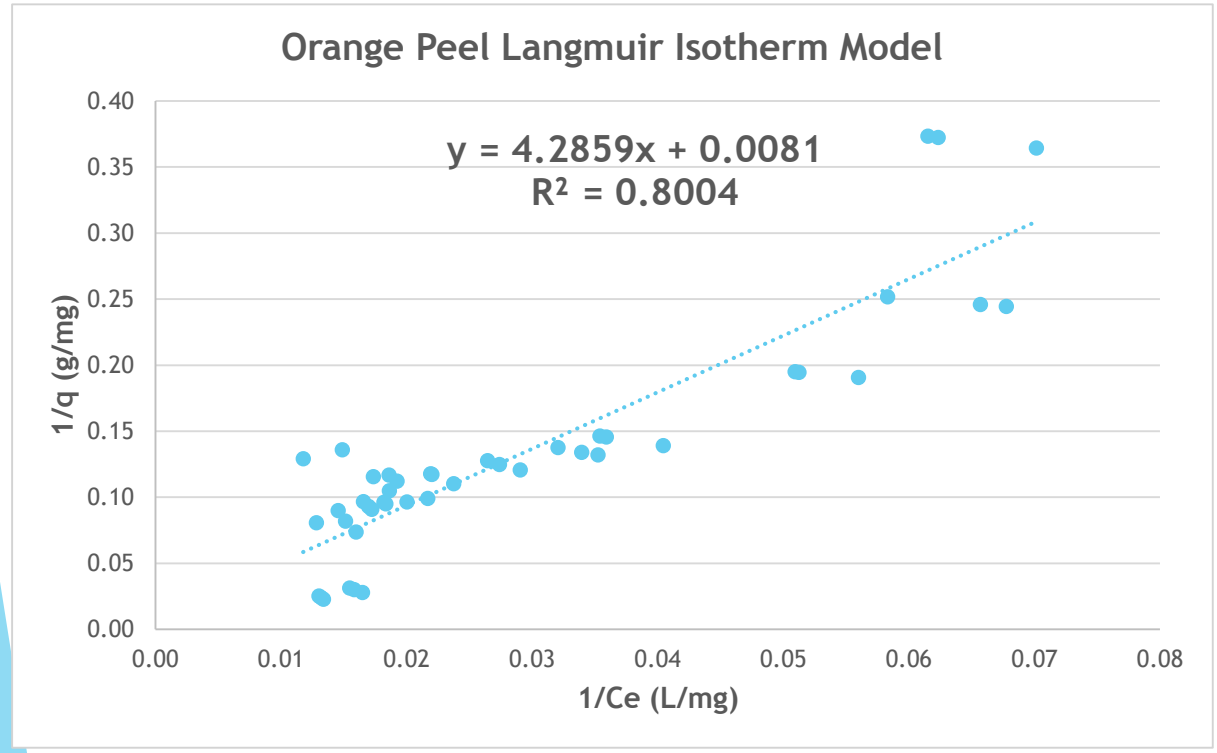


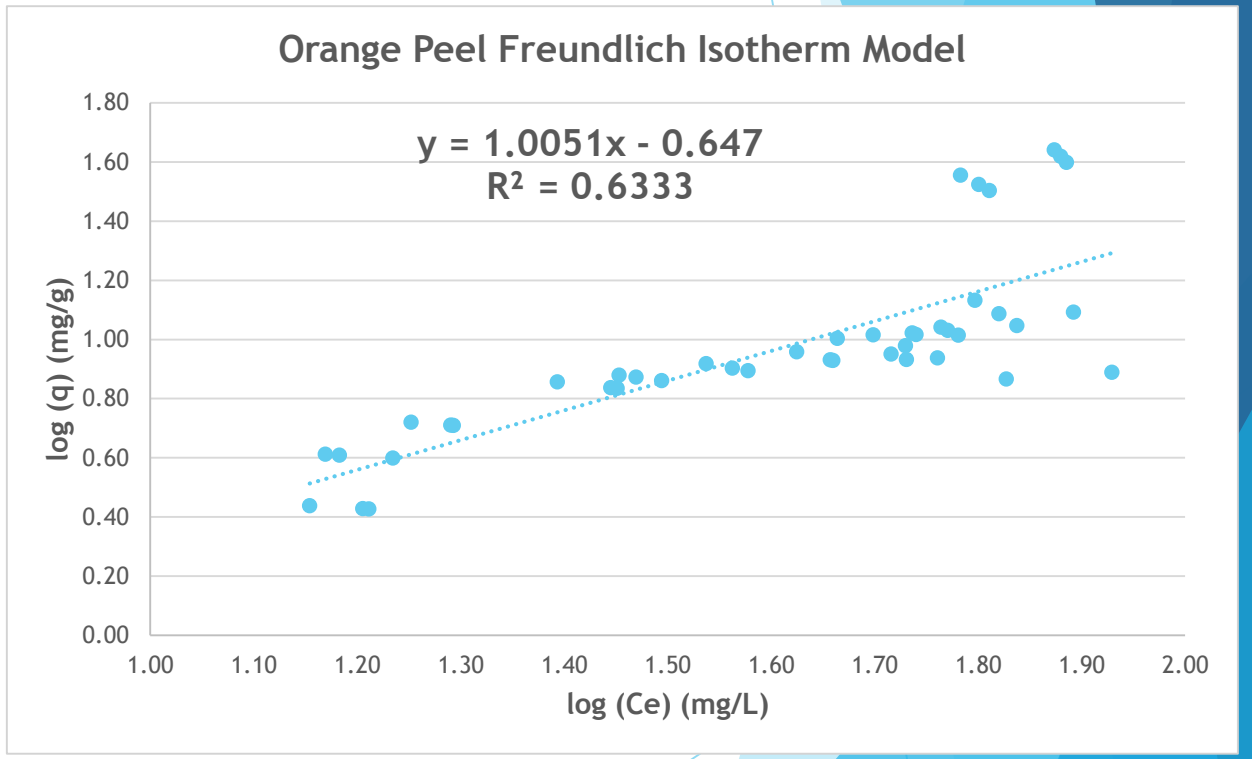


5.0 Data Analysis – Orange Peels

$$\frac{1}{q} = \frac{1}{Q_0} + \frac{1}{Q_0 K_L C_e}$$

$$\log q = \log K + \frac{1}{n} \log C$$

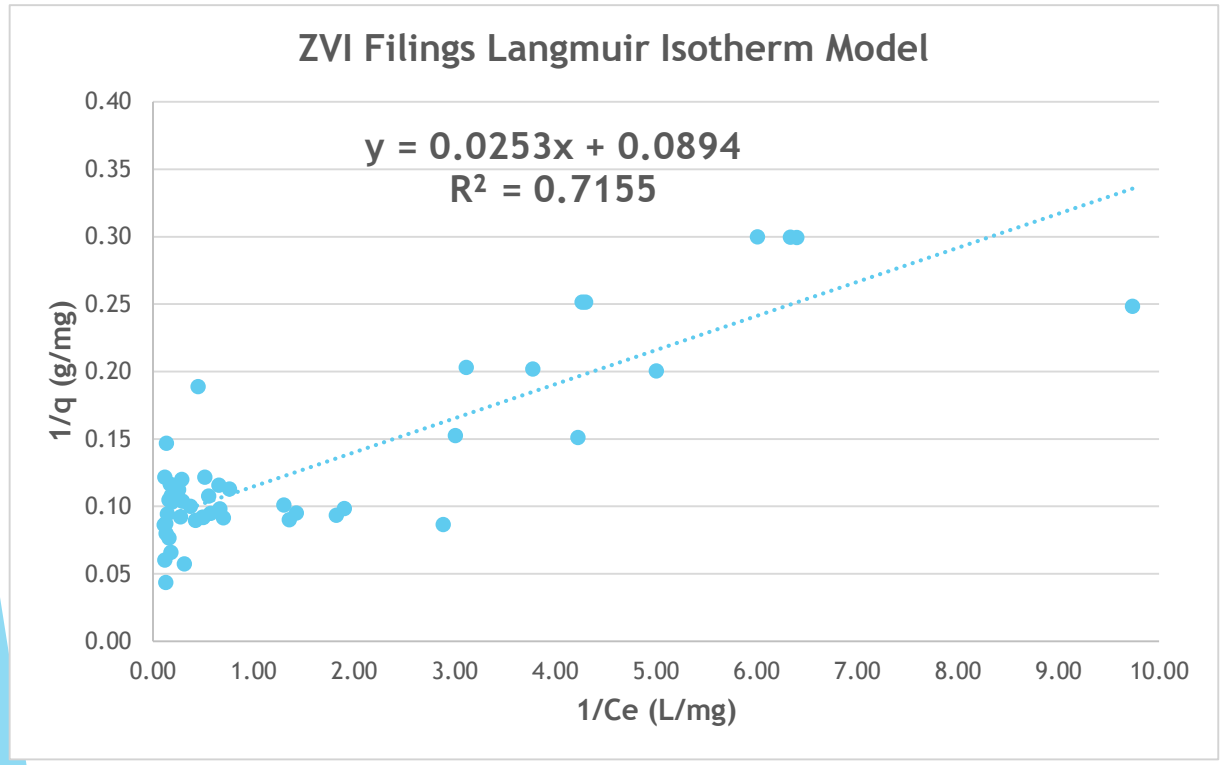


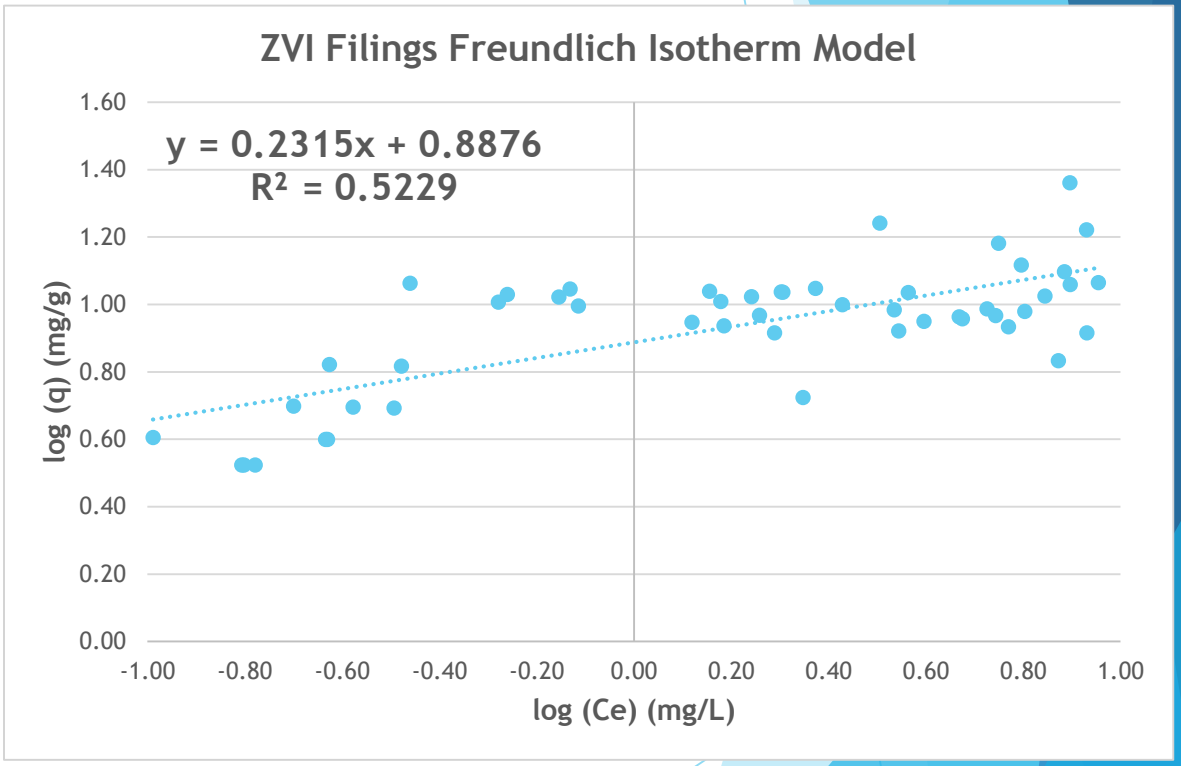


5.0 Data Analysis – ZVI Filings

$$\frac{1}{q} = \frac{1}{Q_0} + \frac{1}{Q_0 K_L C_e}$$

$$\log q = \log K + \frac{1}{n} \log C$$





5.0 Data Analysis

Orange Peel Langmuir Isotherm Parameters

- Q_0 = 123.47 mg/g
- K_L = 1.89E-3 L/mg
- R_L= 0.458

ZVI Filings Langmuir Isotherm Parameters

- Q_0 = 11.19 mg/g
- K_L = 3.53 L/mg
- R_L= 0.03
  - Between 0-1: Favorable for adsorption

6.0 Conclusions & Recommendations

- Orange peels & ZVI filings favorable for adsorption

- Example Scenario #1
  - Initial uranium concentration: 90 µg/L
  - Desired final concentration: 30 µg/L
  - q = 0.007 mg U/g OP
  - Required to treat 10 L: 85.71 g OP

- Recommendations
  - Test for kinetics
  - Design filters

- Example Scenario #2
  - Initial arsenic concentration: 70 µg/L
  - Desired final concentration: 10 µg/L
  - q = 0.38 mg As/g ZVI filings
  - Required to treat 10 L: 1.58 g ZVI Filings

7.0 Project Impacts

- Increase public & ecological health in areas impacted by uranium and arsenic contamination
- Develop industry in simple DIY filters
- Promote sustainable water treatment methods
- Increase public awareness of metal contamination in drinking water

Photo Credit: Hussain Alkandari

8.0 Summary of Project Costs

Item	Classification	Hours	Rate ($/hr)	Cost
1.0 Personnel	SENG	46	146	$6,716
	ENG	213	81	$17,253
	LAB	45	48	$2,160
	INT	12	22	$264
	AA	61	50	$3,050
	Total Personnel	**377**		**$29,443**
2.0 Subcontract	Analytical			$300
	150 samples + 2 Shipments			
3.0 Materials	Orange Peels & ZVI Filings			$60
		Total Cost:		**$29,803**

SENG – Senior Engineer
ENG – Engineer
LAB – Lab Technician
INT – Intern
AA – Administrative Assistant

Subcontract:
Dr. Michael Ketterer, Chemistry Department Professor and Chair, Metropolitan State University of Denver

Acknowledgements

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- Dr. Bridget Bero, NAU CECMEE Department Chair
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- Adam Bringhurst, NAU CECMEE Instructor
- Dr. Derek Sonderegger, NAU Statistics Consulting Lab
- Dr. Michael Ketterer, Metropolitan State University of Denver

References

- [1] D. Cummings, C. Dilks, Y. Sun, & T. Weir, “Final Design Report: Water Filter for Uranium, Arsenic and Bacteria Removal,” Northern Arizona University, Flagstaff, Arizona. May 1st, 2014.