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Factors affecting arsenic removal performance of an iron oxide adsorbent media: An evaluation using RSSCTs

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Motivation

- To determine a relationship between arsenic adsorption media performance and pH, Si, As, V, and EBCT.

- Compiled a database of pilot data, full scale data, and RSSCTs for various adsorbents and water chemistries. There was still a large amount of missing data to accurately predict how the media will perform under a much wider variety of water chemistries.

- A full or pilot scale study on a number of water chemistries would take years to tens of years to complete. The use of rapid small-scale column tests (RSSCTs) allows us to obtain performance data in a matter of days to weeks.

Findings in past studies

- What about water chemistry?
  - Performance of adsorptive media is highly dependent on water chemistry! A broad variation in water chemistry must be studied.

- Why iron oxide media?
  - Iron oxide adsorbent media (E33) for arsenic removal has been broadly used and studied. This media has also shown to be one of the better performers in pilot studies conducted by SNL. It is a good baseline media for a comprehensive water chemistry study.

- Do RSSCTs work?
  - RSSCT data for E33 has proven reproducible and accurately predicts the performance of pilot studies using a proportional diffusivity design.

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The Experiments

Variables in Water Chemistry & Design

Parameter	"High" Value	"Low" Value
Arsenic*	100 ug/L	20 ug/L
Vanadium*	60 ug/L	0
Silica*	60 mg/L	0
pH*	9.0	5.0
EBCT (simulated)	5 min	3 min

* Nationwide groundwater concentration ranges for these constituents are taken from the USGS NAWQA Data Warehouse for Groundwater

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NSF/ANSI 53 Challenge Water

Begin with DI water and add…

Constituent	Concentration	Units
Magnesium, Mg^{2+}	12	mg/L
Nitrate, NO^{3-}	2	mg/L as N
Fluoride, F^-	1	mg/L
Phosphate, PO_4^{3-}	0.04	mg/L as P
Calcium, Ca^{2+}	40	mg/L
Free chlorine	0.25 – 0.75	mg/L Cl_2

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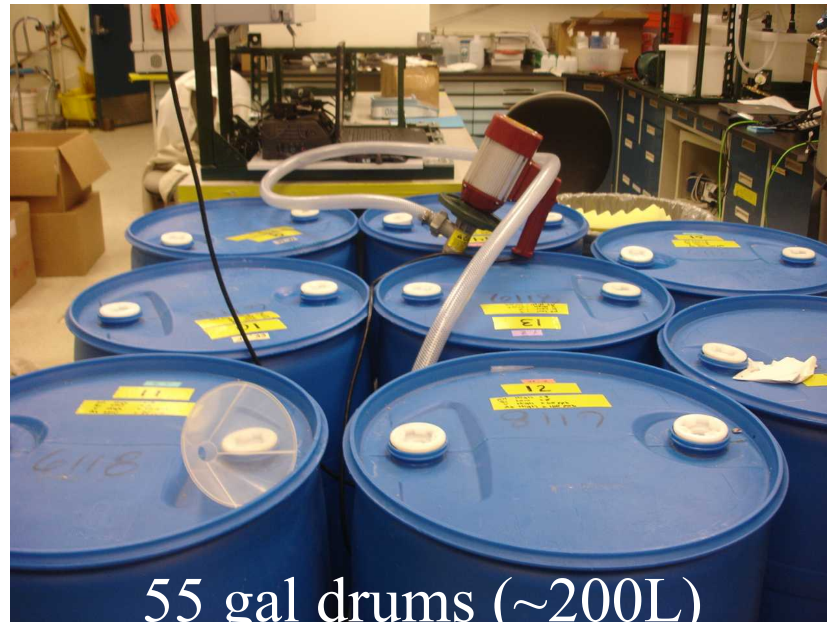
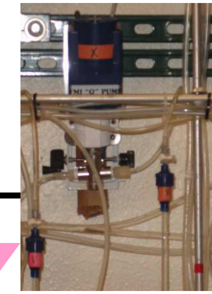
Making water out of water – simulated groundwater

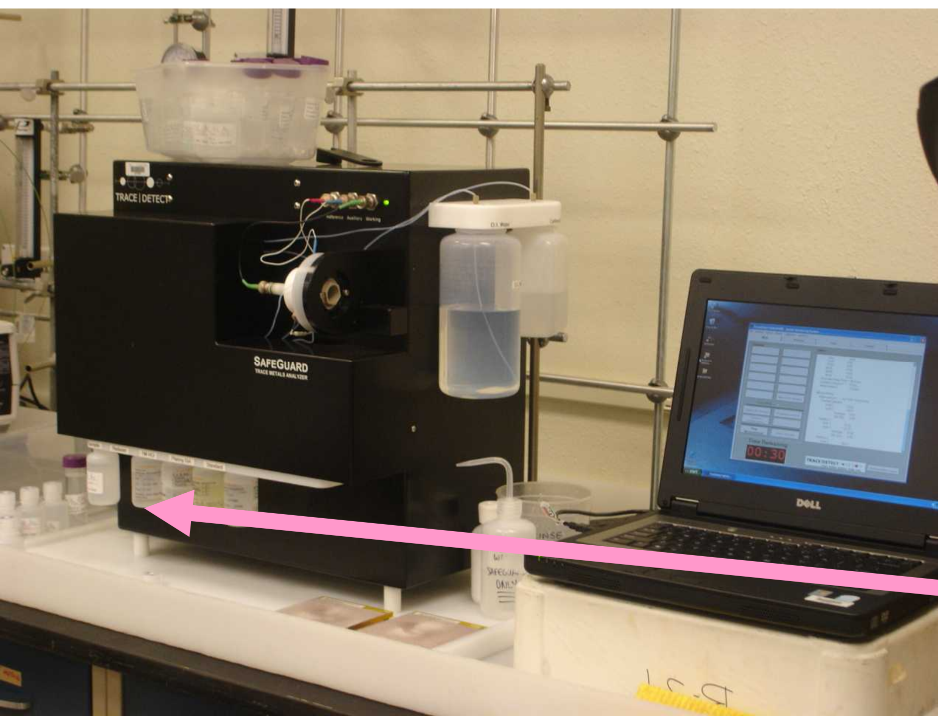
pH	Si (ppm)	V (ppb)	As (ppb)
5	60	60	20
5	60	60	100
5	60	0	100
5	60	0	20
5	0	60	20
5	0	0	20
5	0	60	100
5	0	0	100
9	60	60	20
9	60	0	100
9	60	60	100
9	60	0	20
9	0	60	20
9	0	60	100
9	0	0	20
9	0	0	100

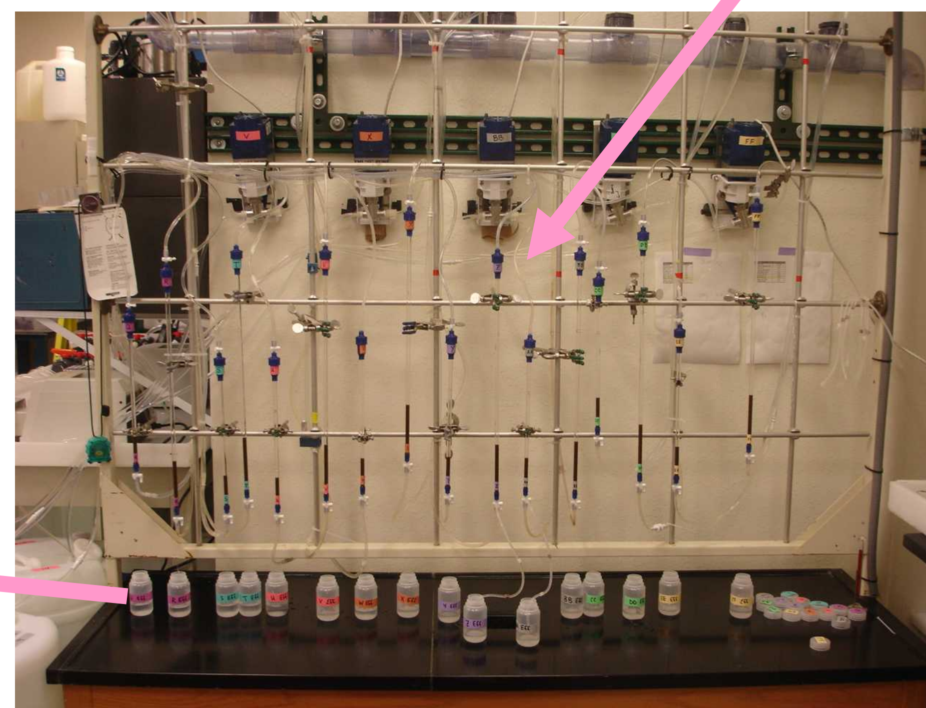


Two column runs per water chemistry (Δ EBCT)

Experimental Setup

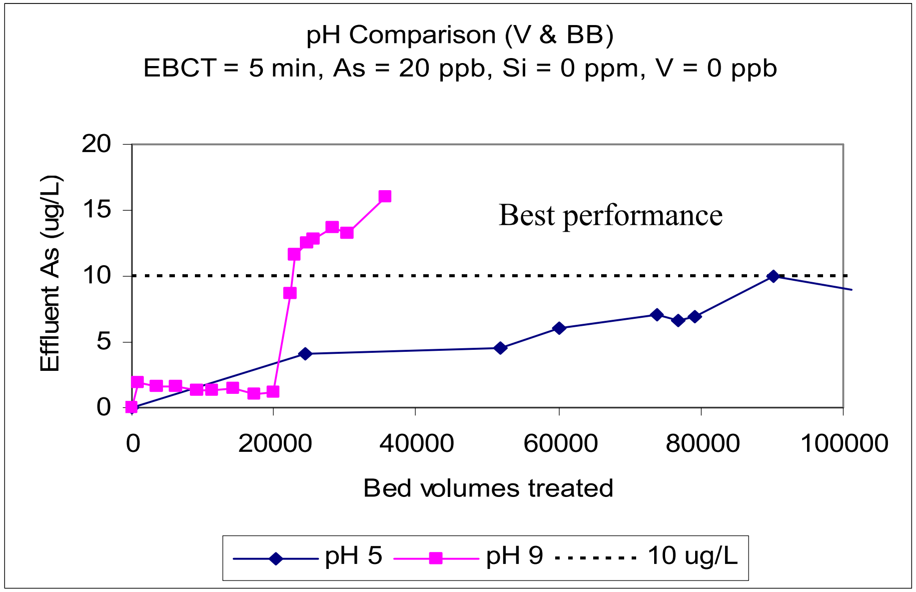






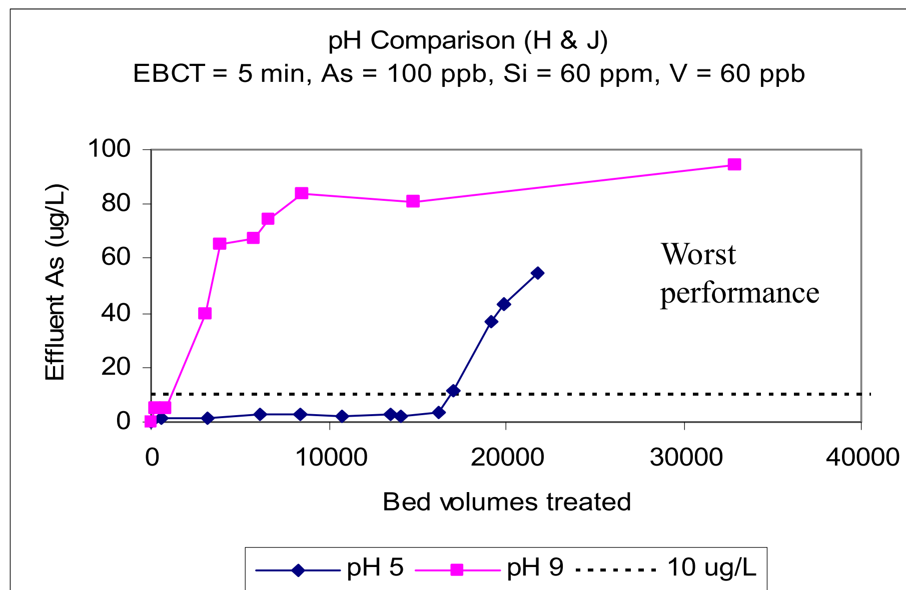
The Results

Arsenic Breakthrough - pH Comparison

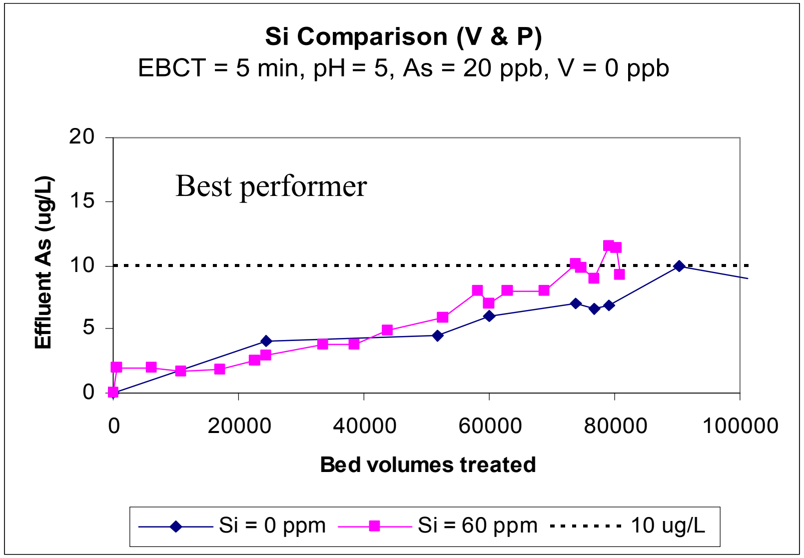


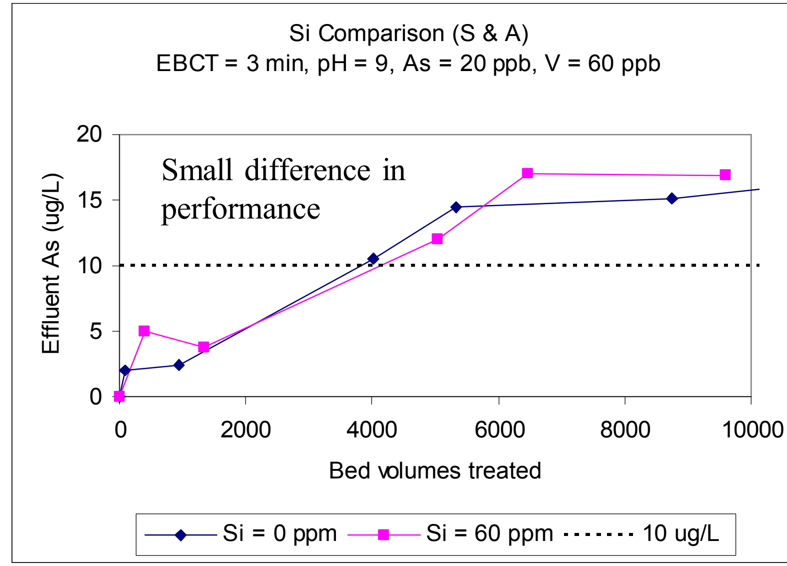
E33 consistently performs MUCH better at pH 5 (vs. pH 9) regardless of other water chemistry parameters

Increase in performance of at least 3x (up to 18x)

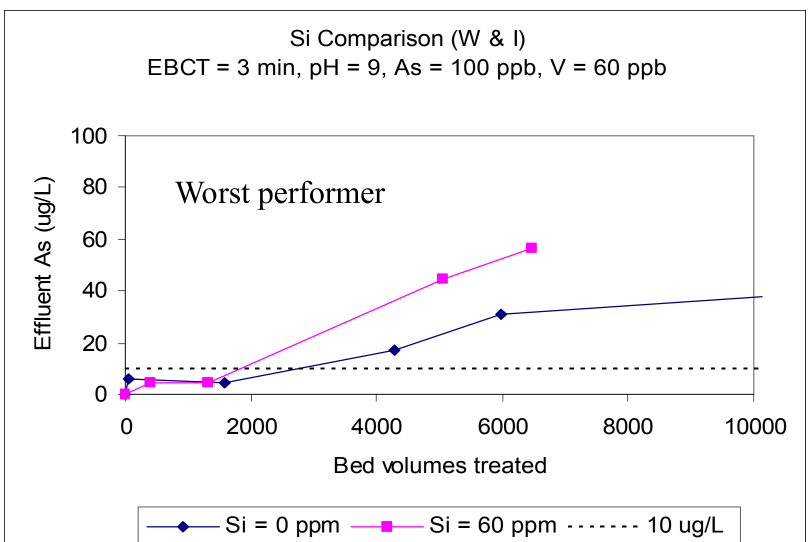


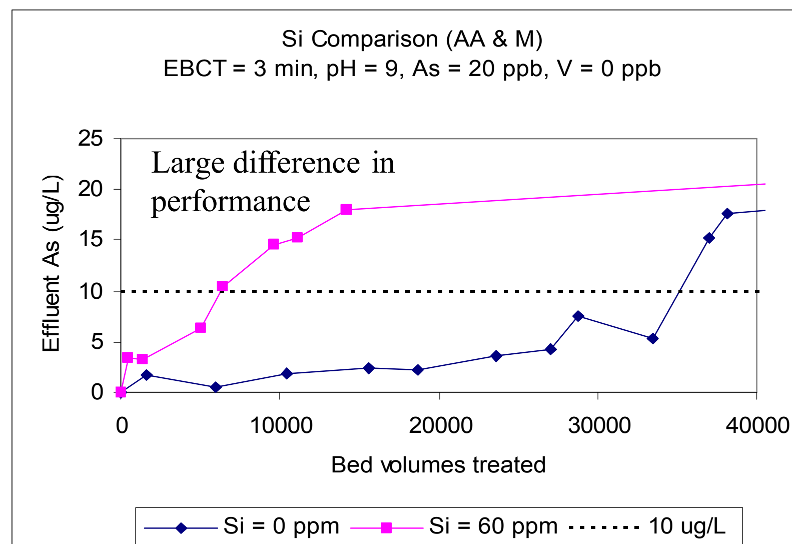
Arsenic Breakthrough - Si Comparison



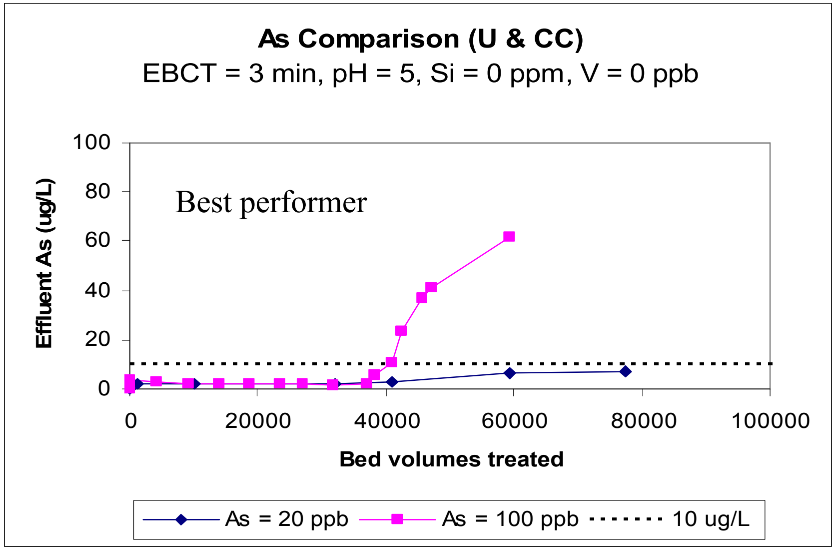


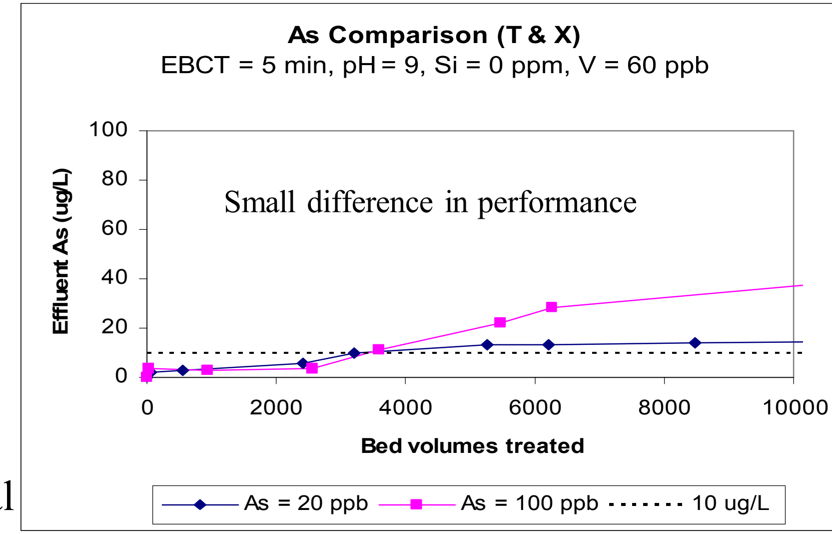
Typical increase 1.2 – 1.6x



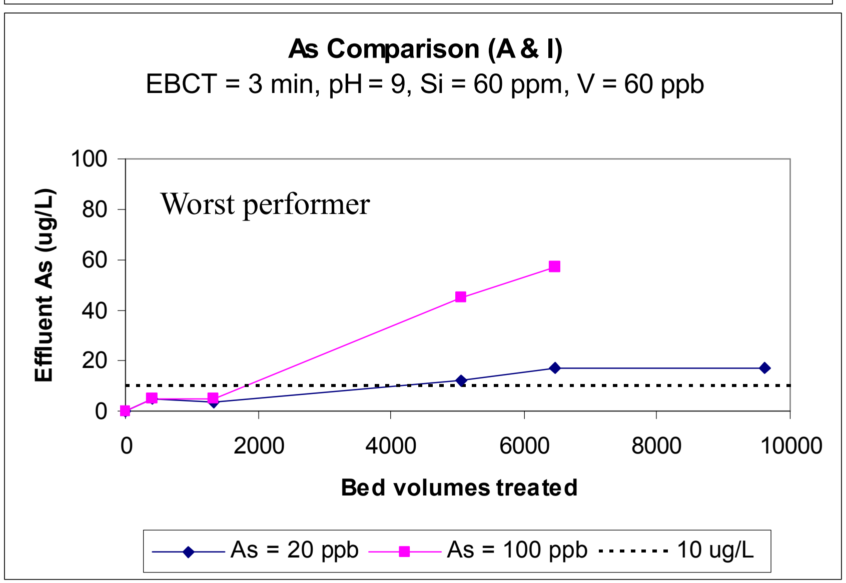


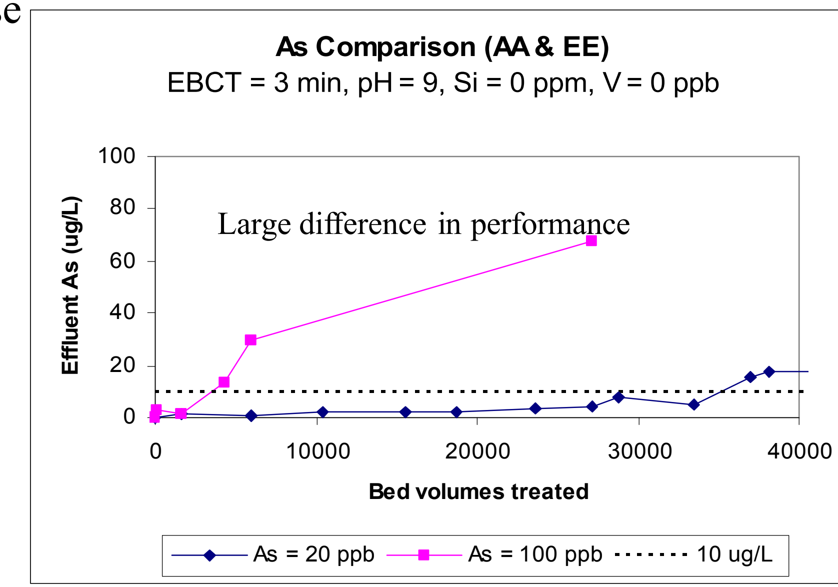
Arsenic Breakthrough - As Comparison



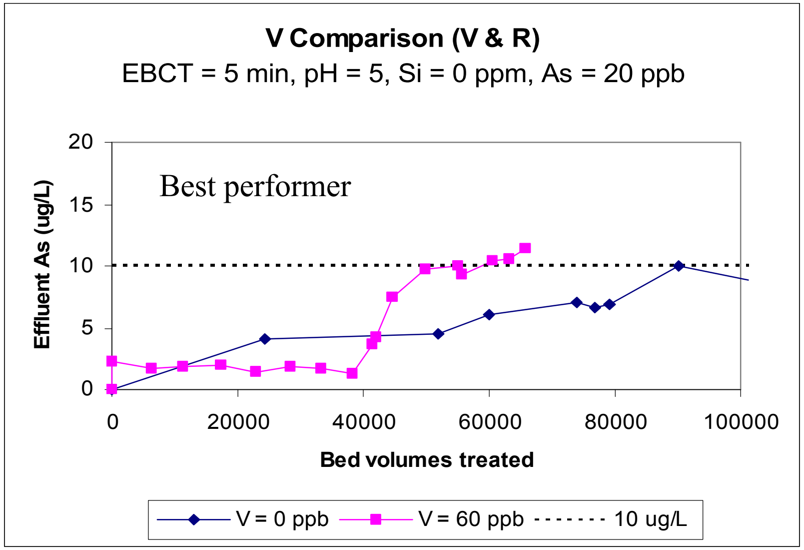


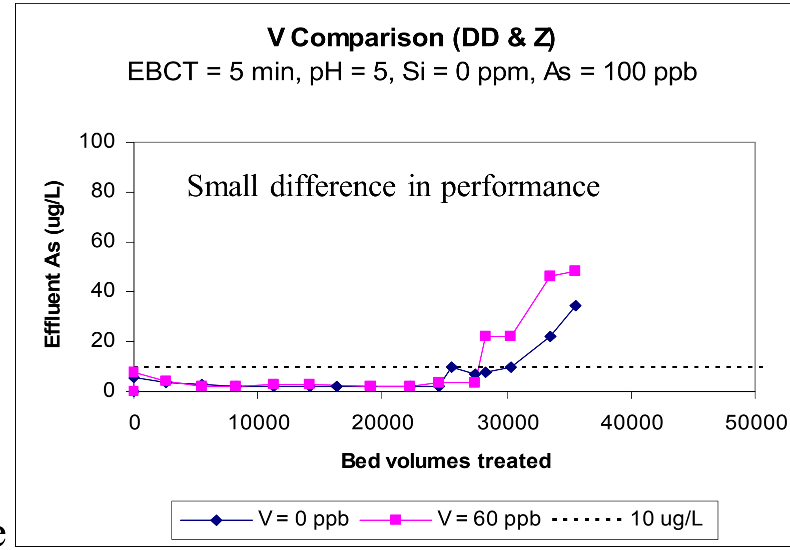
Typical increase 1.5 – 3.3x



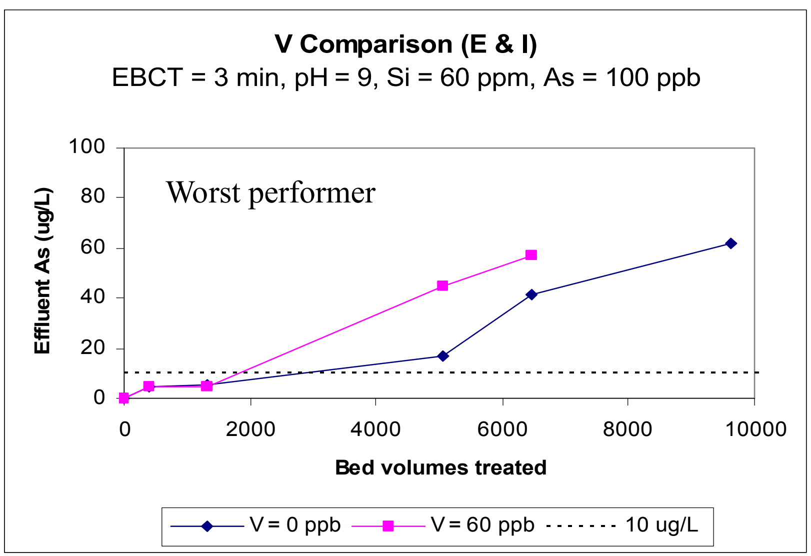


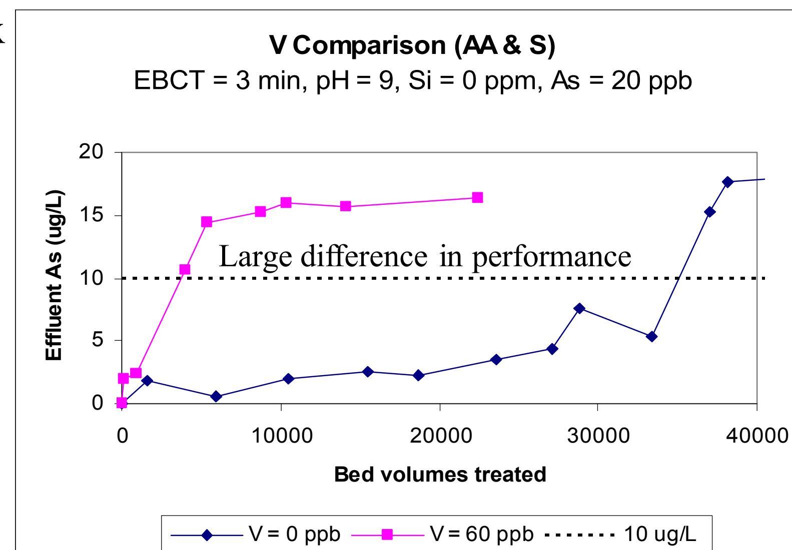
Arsenic Breakthrough - V Comparison





Typical increase 1.1 – 3x

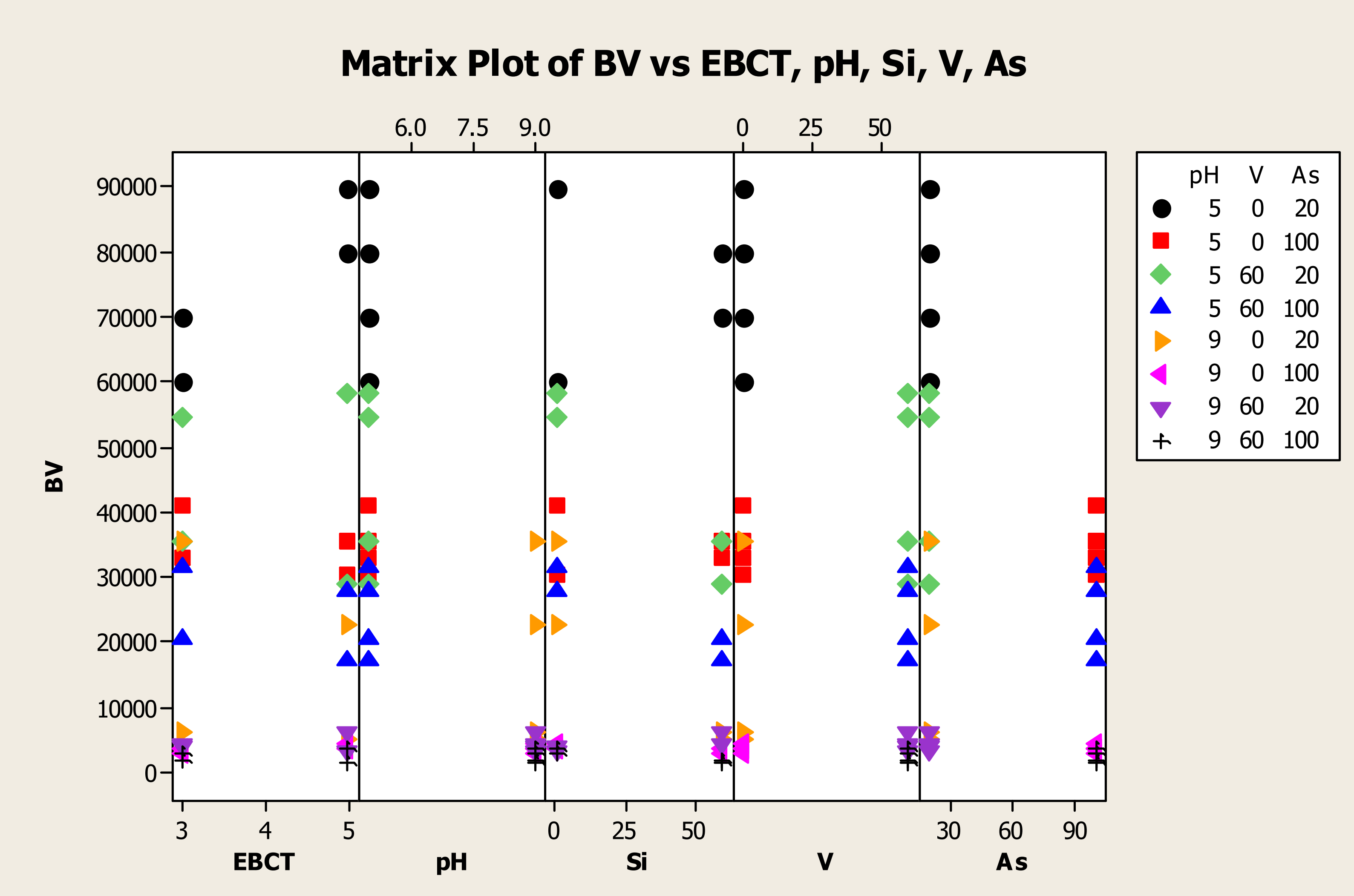




Qualitative Results

- ‘Performance’ is measured by the amount of bed volumes treated until arsenic breakthrough of 10 ug/L
- E33 performs best under conditions low pH, As, Si, and V
- E33 performs poorly under conditions of high pH, As, Si, and V
- High pH seems to be the most consistent culprit for early breakthrough. pH adjustment is recommended for high pH waters.
- High silica and pH tend to plug media requiring more frequent backwashing.
- Higher influent arsenic concentration results in earlier breakthrough

Performance Dependence



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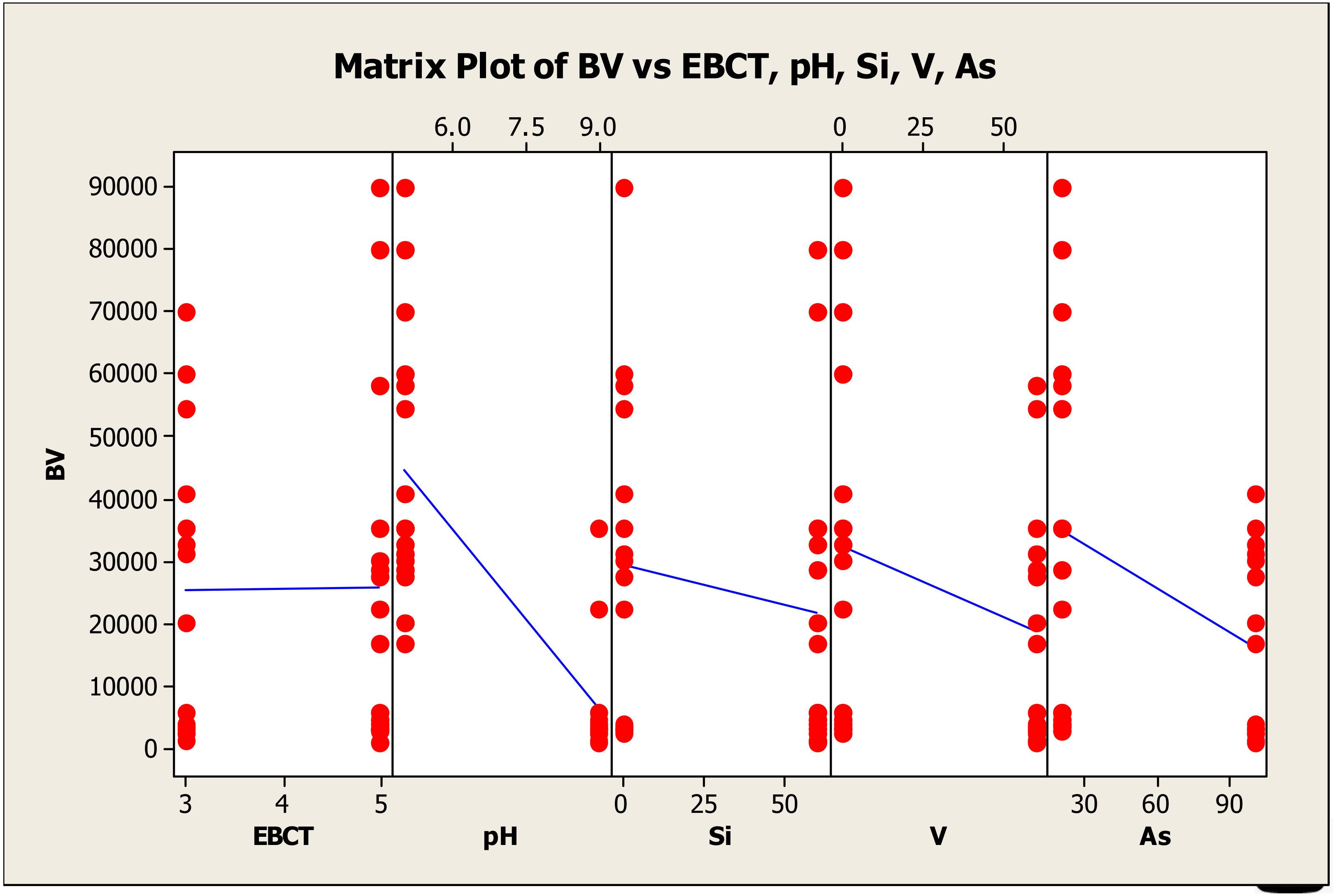
Performance Dependence



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Statistical Analysis – MINITAB[14]

- **How important are the factors (EBCT, pH, Si, V, and As) in predicting the performance (BV treated)?**

- **Multiple Regression Analysis**
  - **Response** – Bed volumes treated to 10 ug/L (BV)
  - **Predictors** – EBCT, pH, Si, V, and As
  - Regression equation:

BV = 115434 + 341 EBCT - 9433 pH - 127 Si - 232 V - 238 As

$R^2 = 82.8\%$

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Statistical Analysis (con't)

- **Best Subsets Regression**
  - What combination of constituents have the greatest effect on performance?
  - Tries all possible multiple regression models – choose best

Vars	R^2	R^2 (adj)	Mallows C-p	EBCT	pH	Si	V	As
1	57.8	56.4	35.9				x	
2	72.6	70.7	15.5		x			x
3	80.5	78.4	5.6		x		x	x
4	**82.8**	**80.3**	**4.0**		**x**	**x**	**x**	**x**
5	82.8	79.5	6.0	x	x	x	x	x

Best subsets chooses a multiple regression model and avoids

- Cumbersome and inefficient models resulting from too many predictors
- Unstable coefficients resulting from redundant and correlated predictors

Statistical Analysis (con't)

- **EBCT is not a significant predictor of BV.**
- **Remove EBCT as predictor in multiple regression**

- **The regression equation becomes:**

BV = 116797 - 9433 pH - 127 Si - 232 V - 238 As

$R^2 = 82.8\%$

This model explains ~83% of the variability in response (BV). There is still 17% uncertainty

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Now what?

- Evaluate the regression model.
- Test the regression equation on pilot and full scale data.
- Perform statistical analysis on entire database – compare regression equations.
- Pin-point the equation that adequately predicts arsenic adsorption performance and give it a really cool name!
- Experimental methods and statistical analyses can be repeated for a variety of other adsorbent media classes.

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Thanks ya'll

- Randy Everett – he rocks!
- Bill Holub – he rolls!
- WQL - Emily Wright, Michelle Shedd, Justin Marbury, Fotini Walton, Andres Sanchez, Carolyn Kirby
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Happy Halloween!