Rapid Small Scale Column Test (RSSCT) – Procedures for Arsenic Studies and Application of Results

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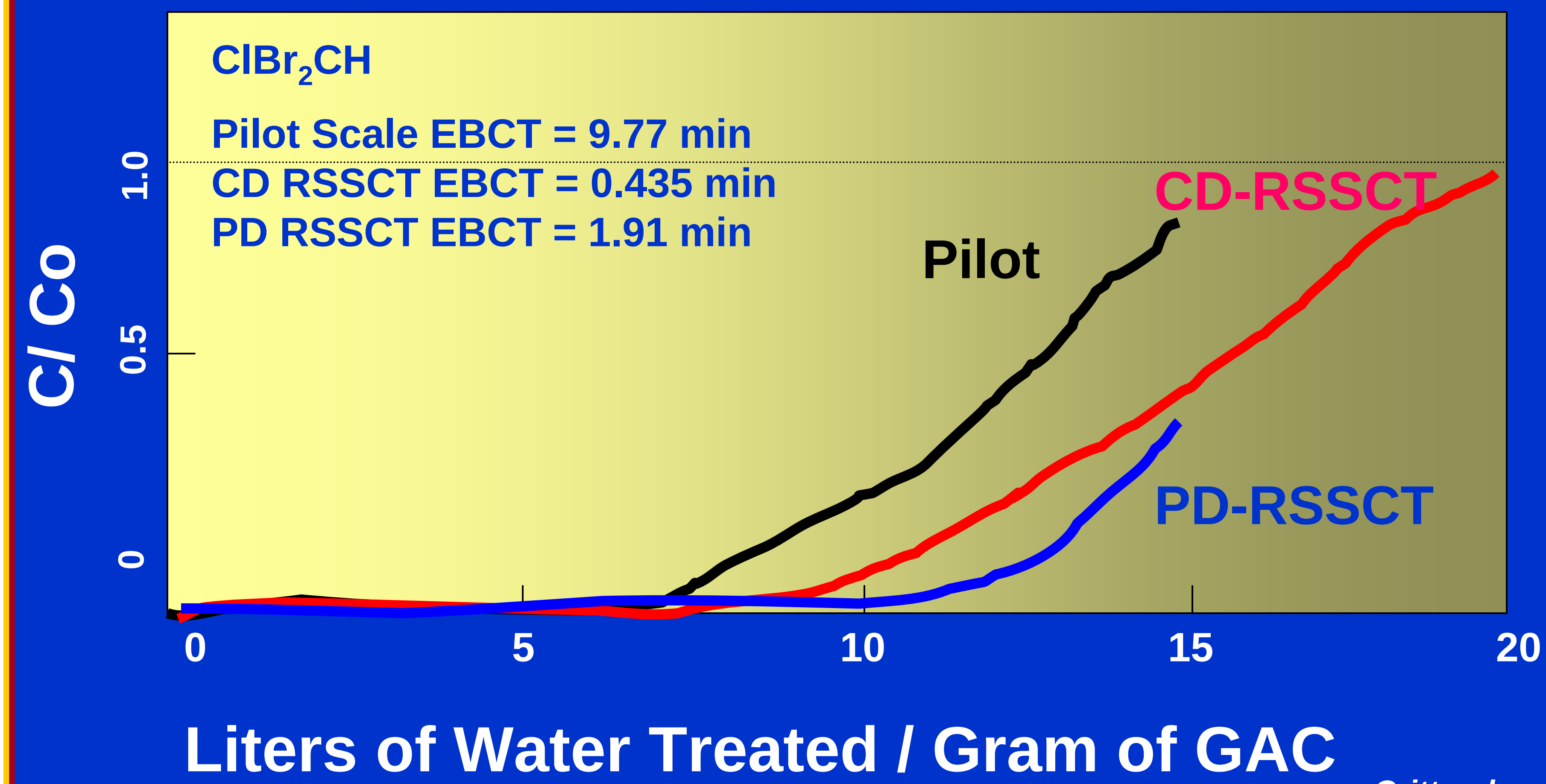
Objectives for Talk

- Describe advantages of RSSCTs for arsenic adsorptive media testing
- Describe basis for applying RSSCTs
- Demonstrate use of RSSCTs

What is an RSSCT?

- Rapid Small Scale Column Tests (RSSCTs) were initially developed by Crittenden and others for evaluating organic compound removal on activated carbon
- Fundamentally, the concept is to scale the hydrodynamics and mass transport from full-sized media in a pilot or full scale reactor *down* to smaller test media in a small-scale bench-top continuous flow test

Rapid Small Scale Column Tests (RSSCTs) For GAC versus Pilot GAC Data



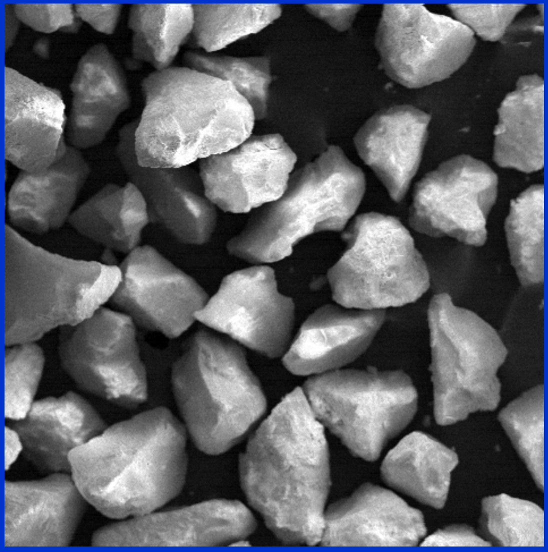
Crittenden et al.

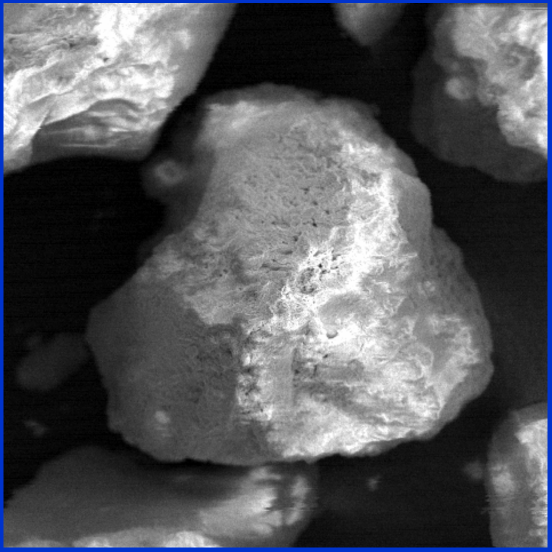
Advantages of RSSCT

- RSSCTs can be conducted in a fraction of the time required of pilot tests (1% to 10% of the time)
- RSSCTs require less water than pilot tests, and can be conducted under controlled laboratory conditions
- RSSCTs are generally cheaper than pilot tests
- RSSCTs are continuous flow tests and allow evaluation of dynamic behavior and competition reactions that are more representative than batch tests
- RSSCTs were used during the USEPA ICR for organic carbon removal
- RSSCTs facilitate comparison of media and water quality effects

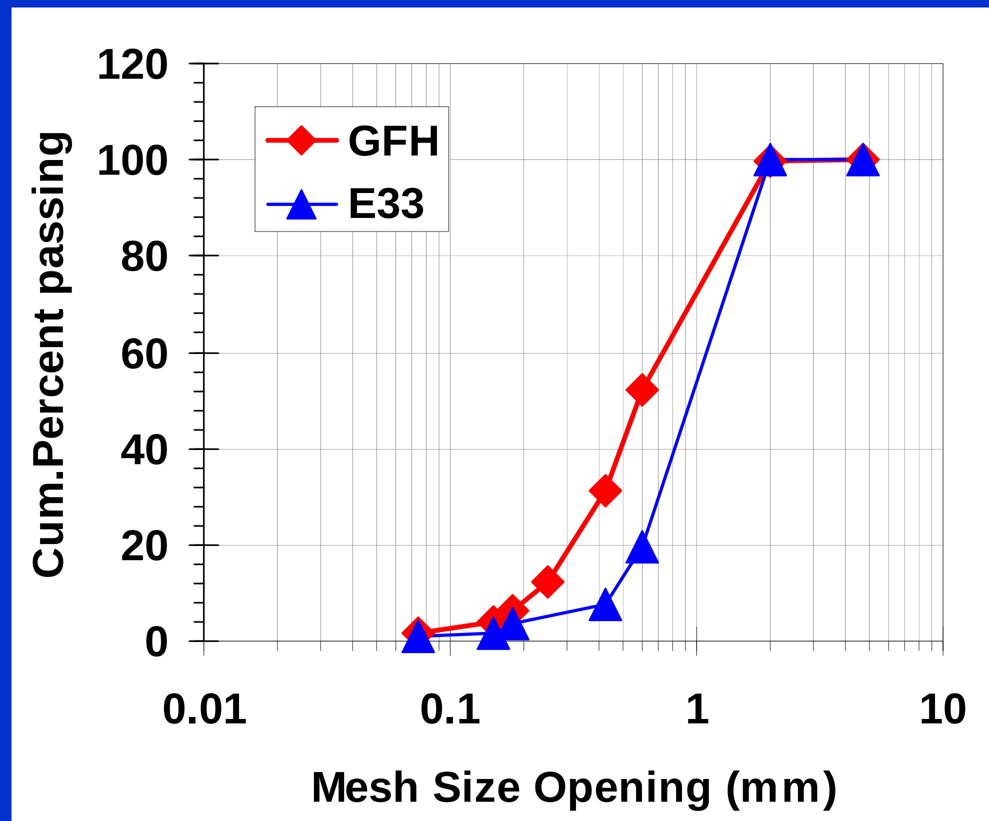
Today's Question

Are RSSCTs suitable for evaluating arsenic removal by porous metal (hydr)oxide medias?



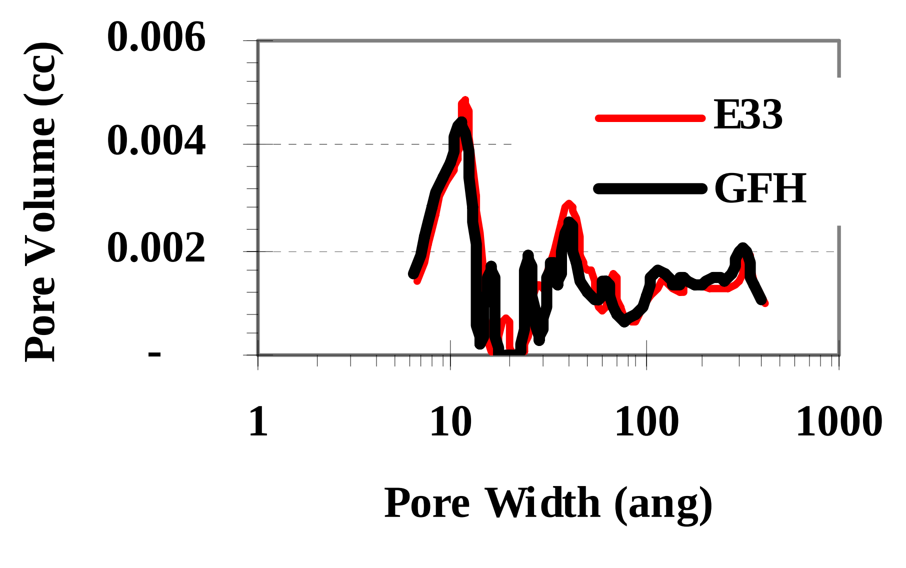


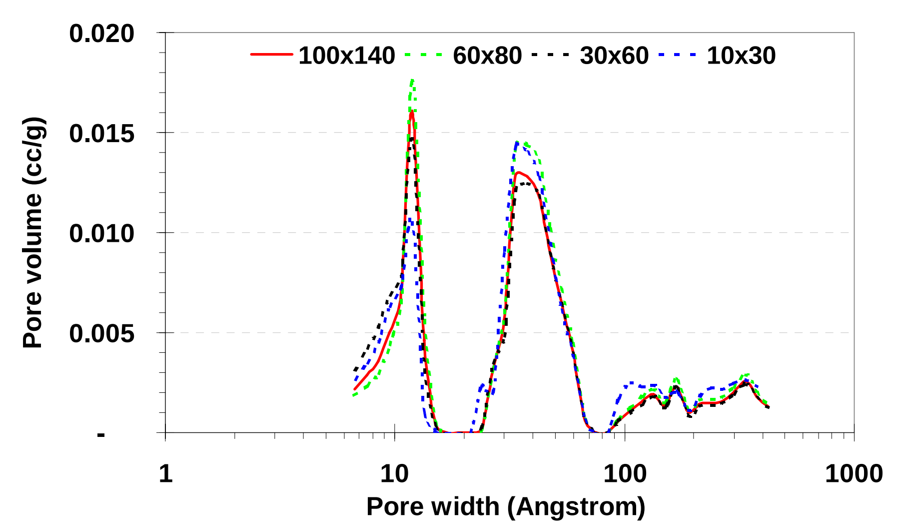
Adsorbent Material Sieved into discrete particle / mesh sizes



Basis for RSSCT

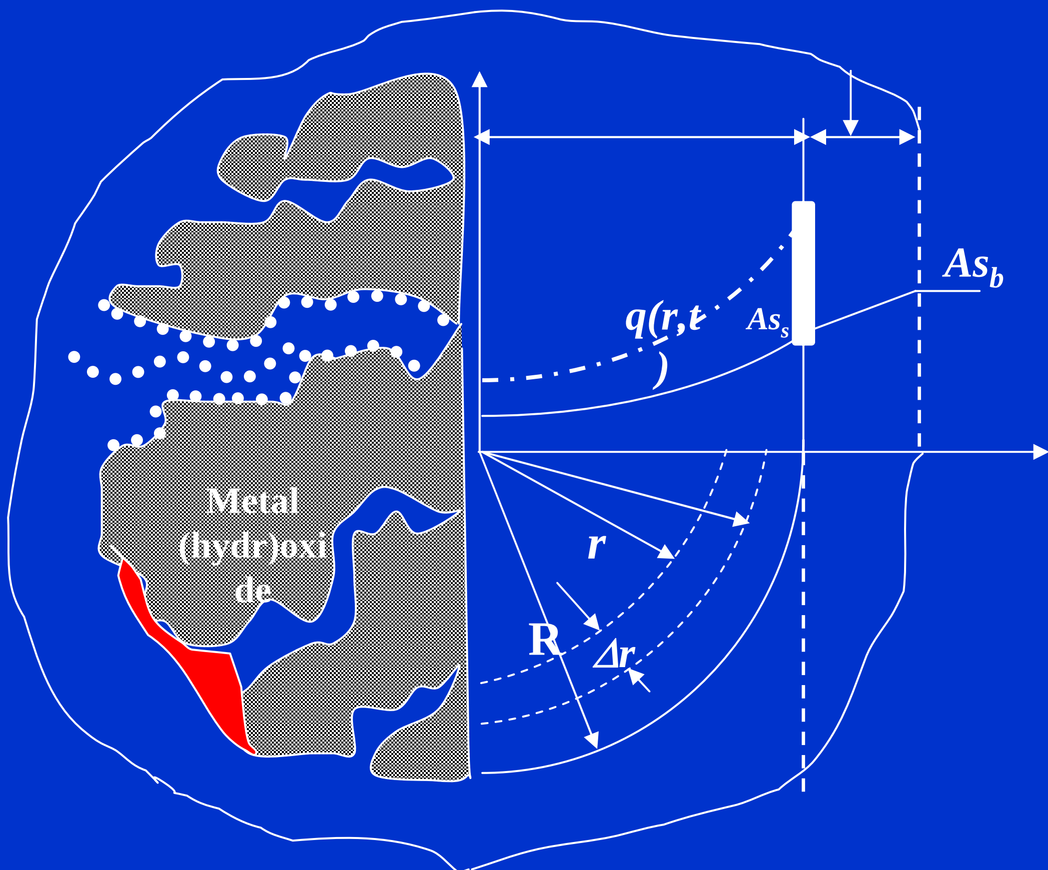
- Key assumption - Internal mass transport is limiting (therefore only applicable to microporous materials)
- GFH surface area is 230 m^2/g and E33 is 130 m^2/g
- GFH and E33 have comparable pore structure
- Pore size distribution is nearly independent of particle radius (r_p) or mesh size
- Conclusion: Internal mass transfer is probably important & RSSCTs could be viable testing technologies





Porous Adsorbents

Bulk Solution



Bulk Solution

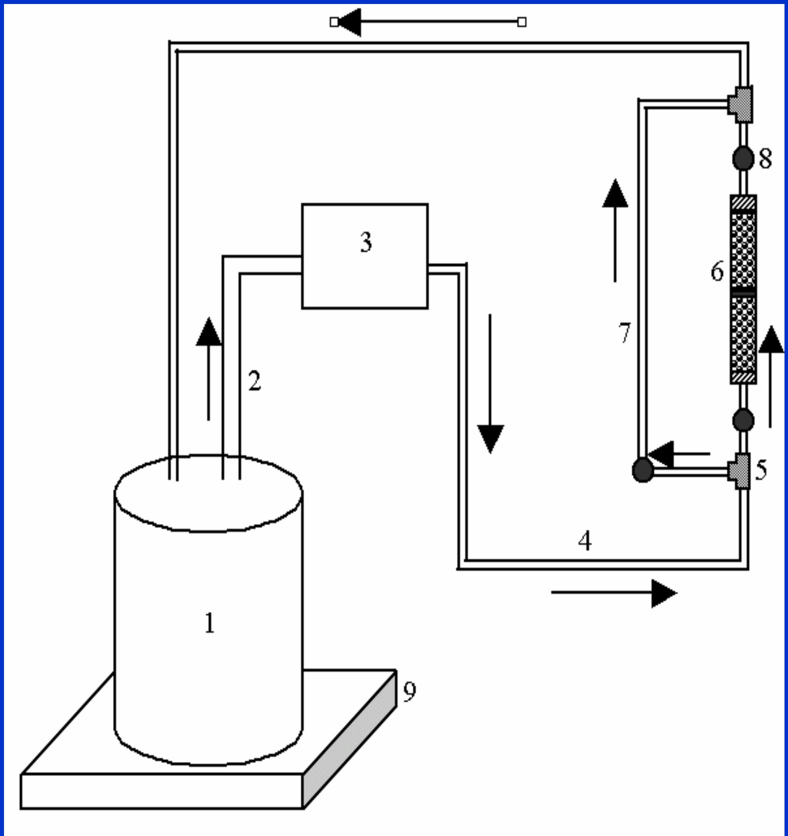
$$\frac{\partial q(r,t)}{\partial t} = D_s\left(\frac{\partial^2 q(r,t)}{\partial r^2} + \frac{2}{r}\frac{\partial q(r,t)}{\partial r}\right)$$

Results

- Differential Column Batch Reactor (DCBR) Study
- RSSCTs with different particle diameters
- RSSCTs versus pilot performance
- Application of RSSCTs for arsenic removal media

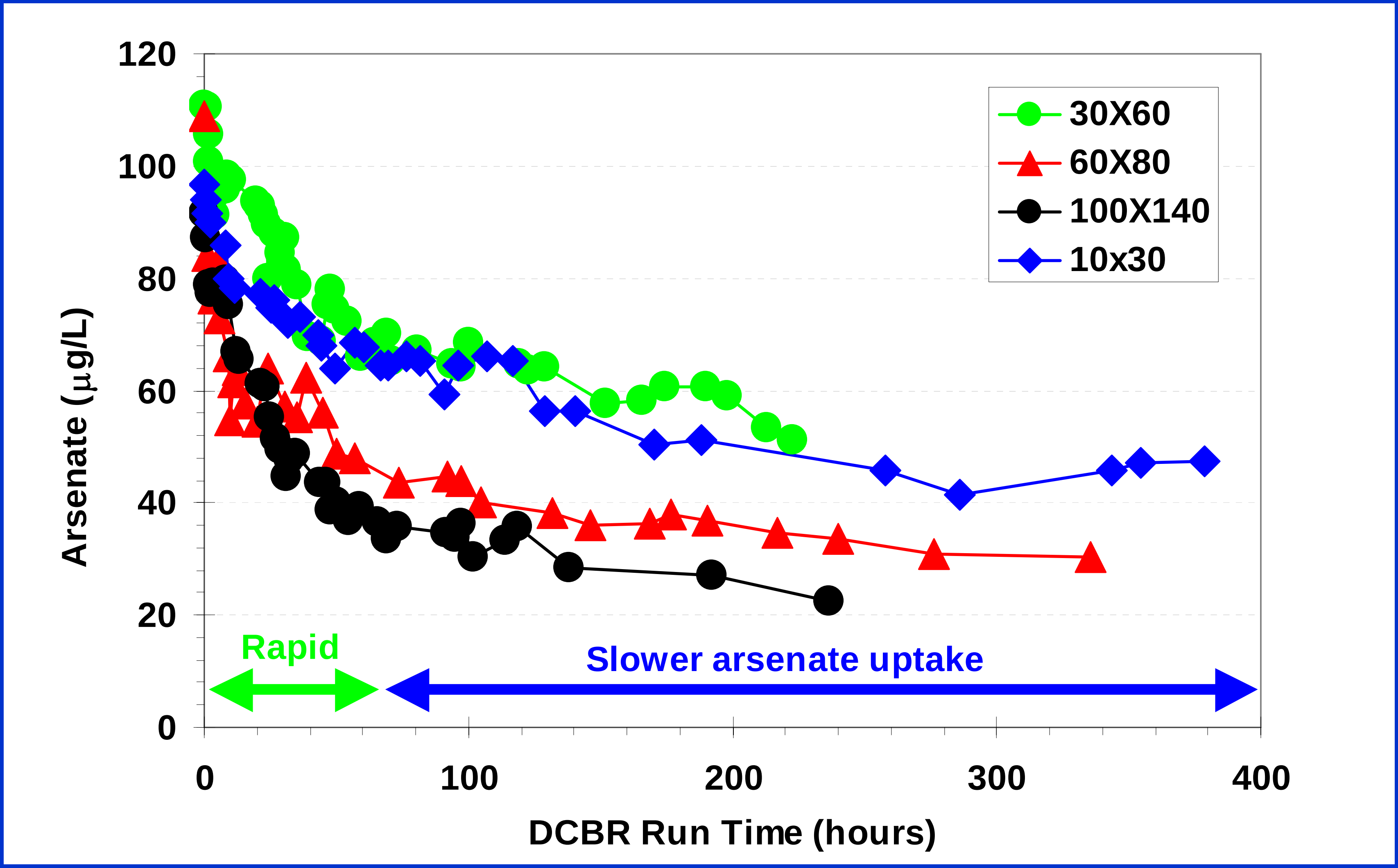
DCBR Apparatus

- DCBR Apparatus is used to determine internal mass transfer coefficients
- Results are used to evaluate applicability of RSSCT scaling theory

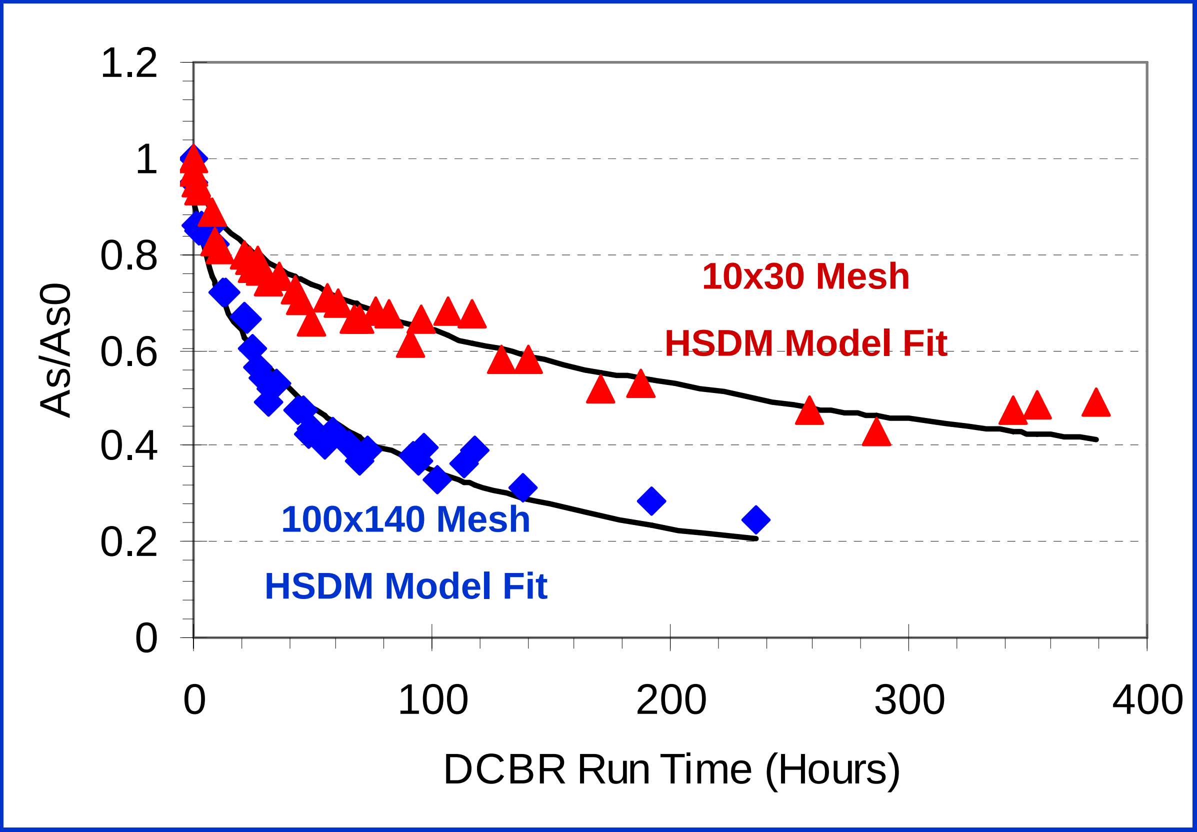


Differential Column Batch Reactor (DCBR)

DCBR Data for Various Mesh Sizes



DCBR Results & Modeling with GFH



Equilibrium Isotherm

$q = K\ C^{1/n}$

K = 4.0 & 1/n = 0.3

$$SPDFR = \frac{\rho_p D_{s(D_p=0)} q_0}{\varepsilon_p D_L As_0}$$

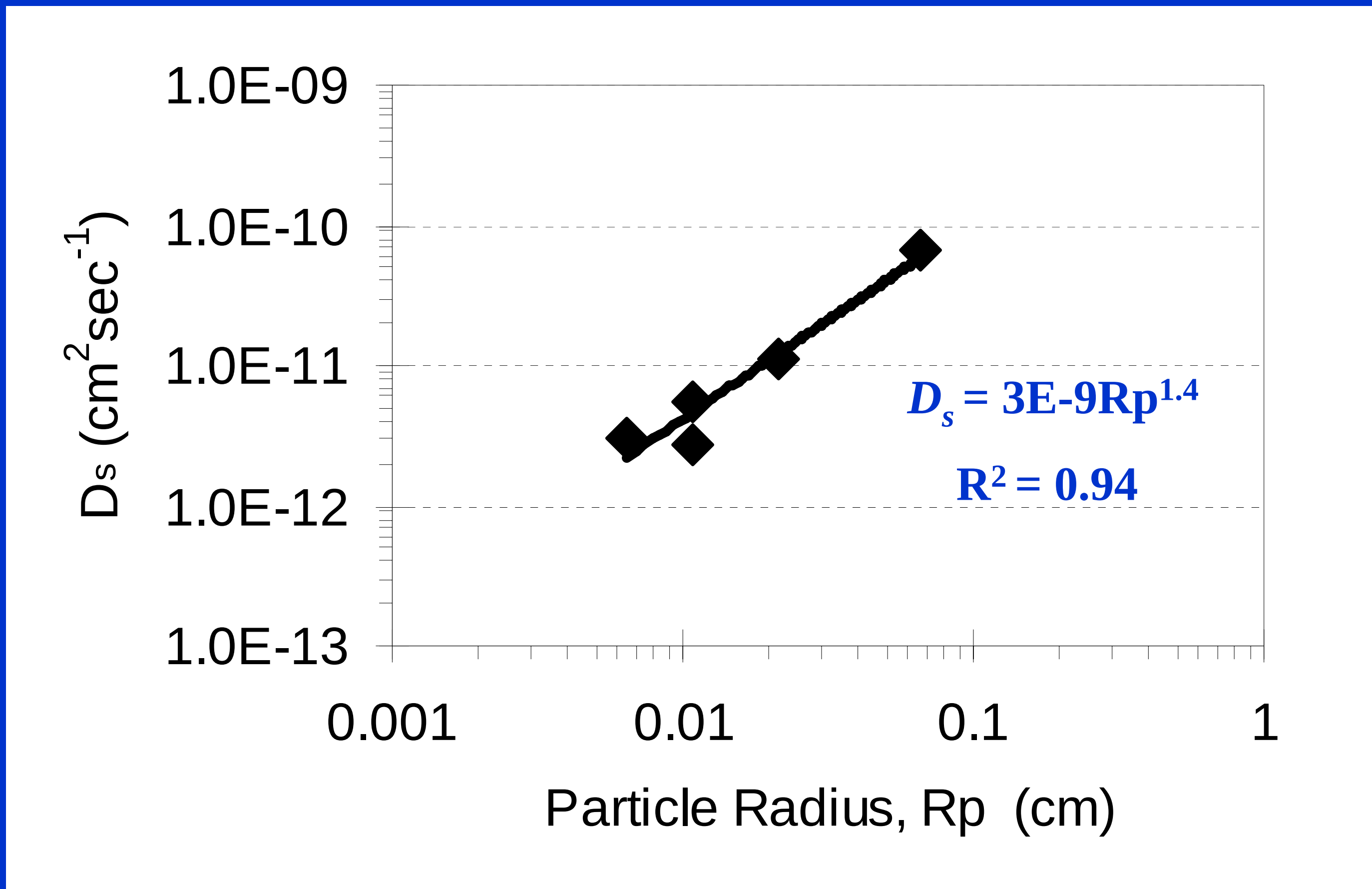
- SPDFR Ranged 6 ~150

$$Bi = \frac{k_f d_p C_0}{2D_s \rho_p q_0}$$

- Bi ranges 7 ~57

$$\frac{\partial q(r,t)}{\partial t} = D_s\left(\frac{\partial^2 q(r,t)}{\partial r^2} + \frac{2}{r}\frac{\partial q(r,t)}{\partial r}\right)$$

Fitted Surface Diffusivities



Conclusion: Surface diffusivity is *not* constant, but proportionate to GFH particle radius

Results

- Differential Column Batch Reactor (DCBR) Study
- **RSSCTs with different particle diameters**
- RSSCTs versus pilot performance
- Application of RSSCTs for arsenic removal media

RSSCT Scaling Relationships

- Empty bed contact times (EBCTs) are scaled based upon particle radius (R)
- Constant Diffusivity (CD)
  - $D_{S,\text{small column media}} \approx D_{s,\text{large column media}}$
  - $R_{SC} \neq R_{LC}$
  - X = 0

$$\frac{EBCT_{SC}}{EBCT_{LC}} = \left(\frac{R_{SC}}{R_{LC}}\right)^{2-x}$$

- Proportional Diffusivity (PD)
  - Diffusivity is proportional to adsorbent radius
  - From D_s data with DCBR
    X = 0.6 (assume X=1)

$$x = \frac{Log\left(\frac{R_{SC}}{R_{LC}}\right)}{Log\left(\frac{D_{s,SC}}{D_{s,LC}}\right)}$$

- PD approach should be valid for GFH

Validating RSSCTs

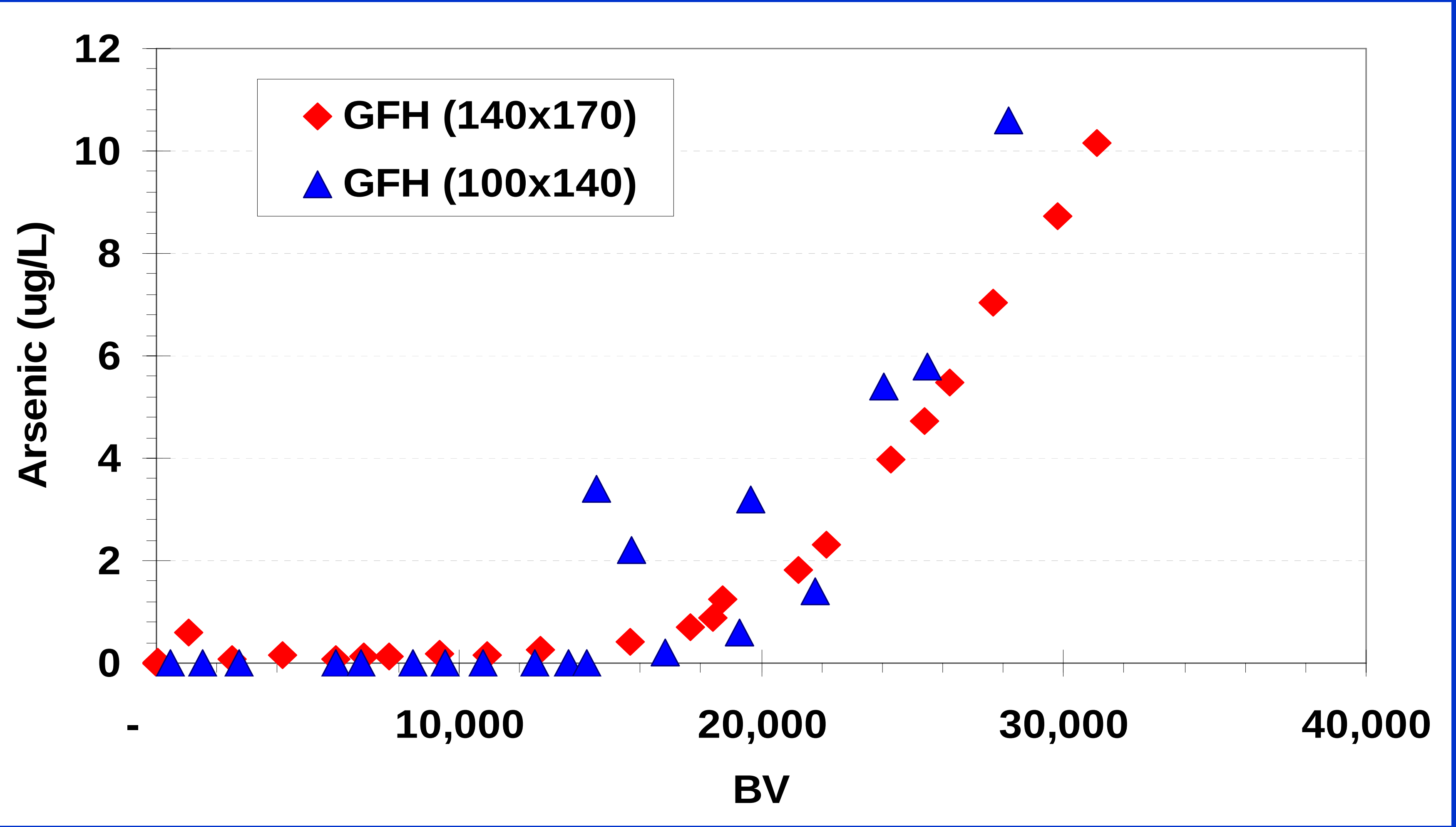
Approach:

Vary Particle Radius (R_{SC}) used in RSSCT columns

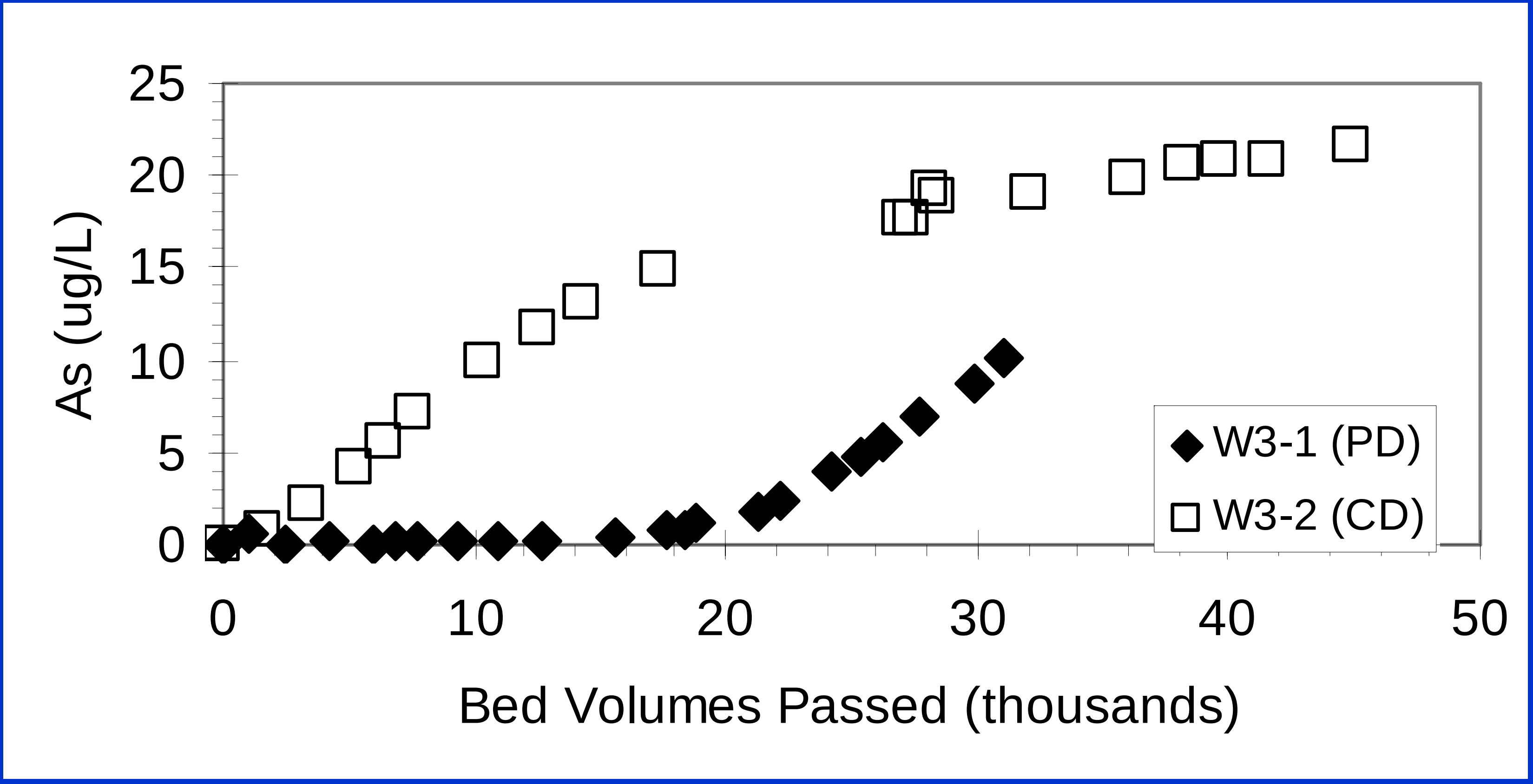
and

scale RSSCTs to a common sized pilot column that uses a larger adsorbent particle radius (R_{LC})

PD Scaling "works" with different GFH Mesh Sizes



Comparison of CD versus PD RSSCTs



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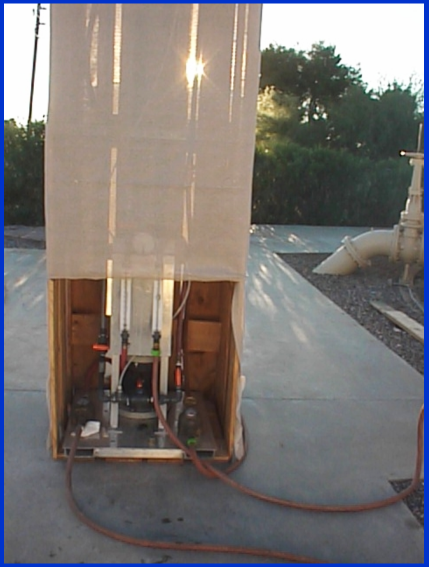
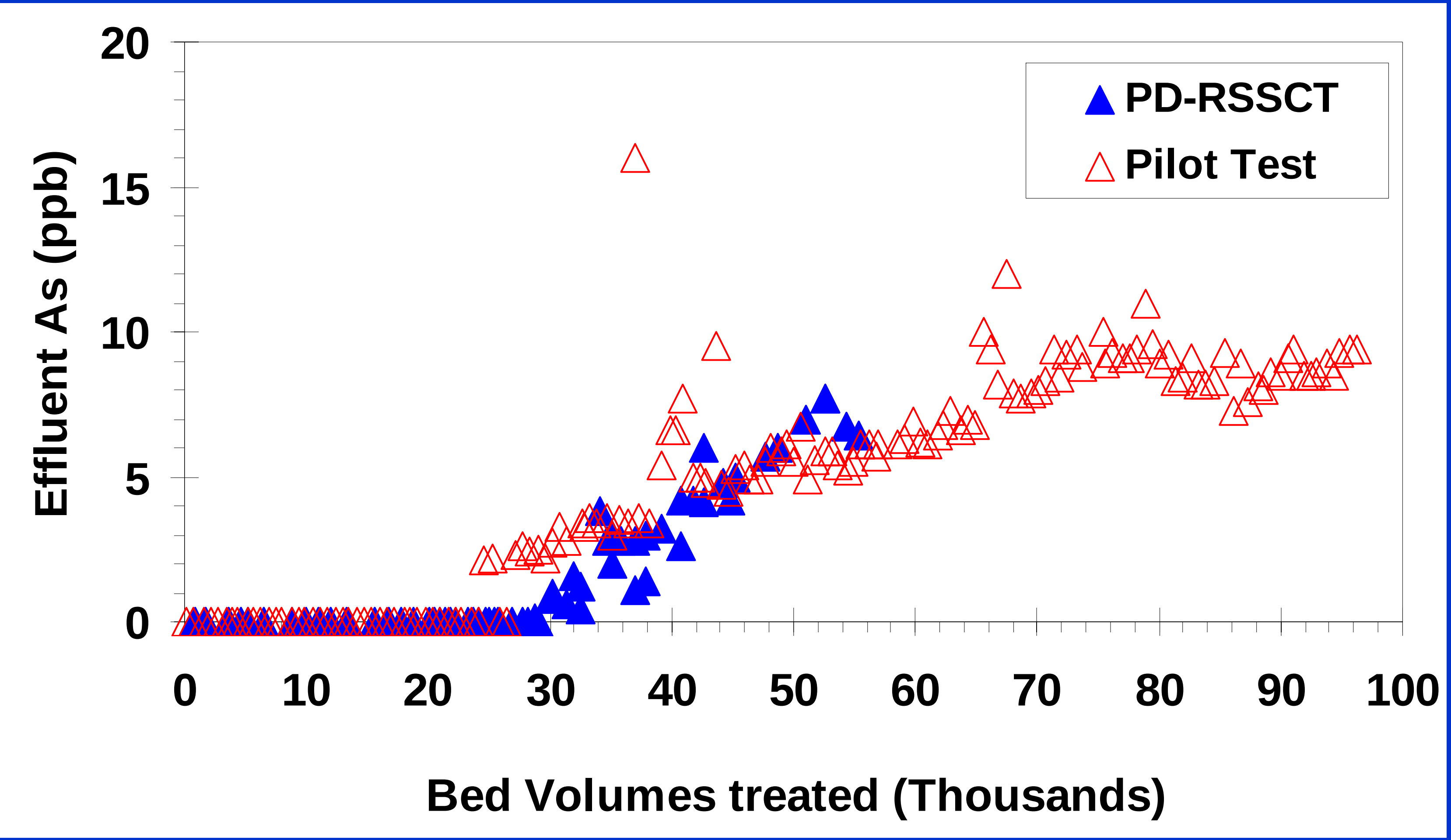
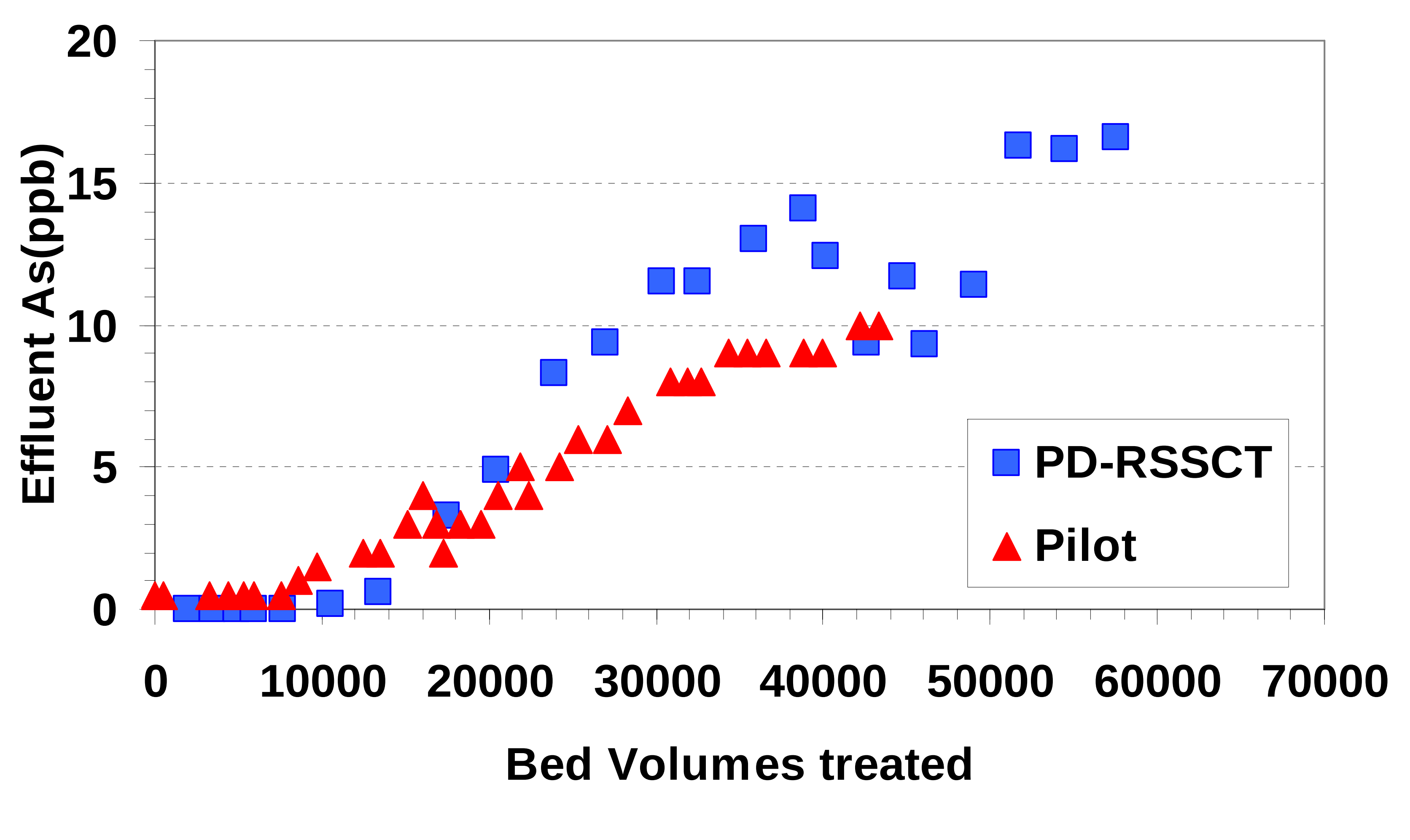


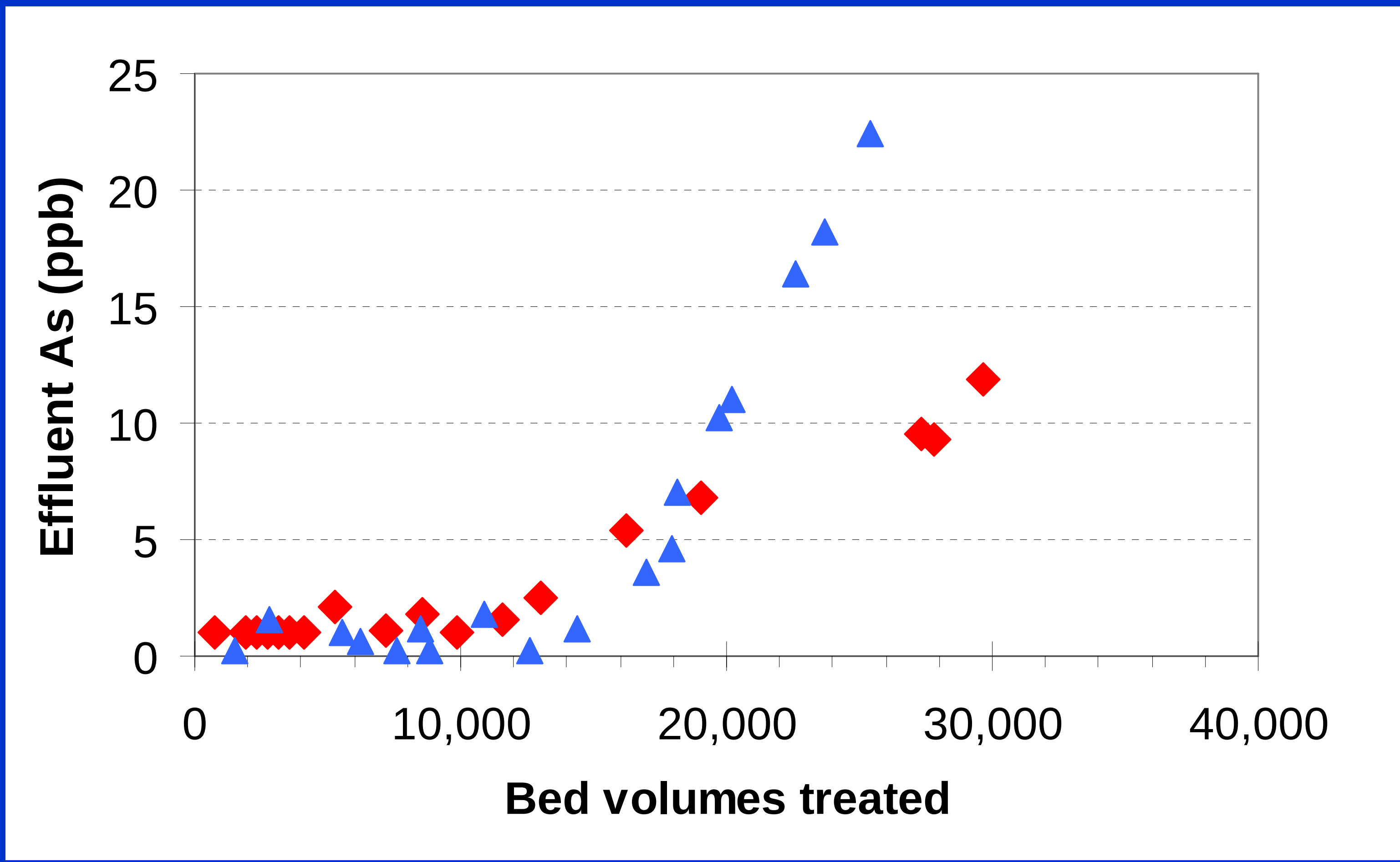
RSSCT-PD vs Pilot (GFH)



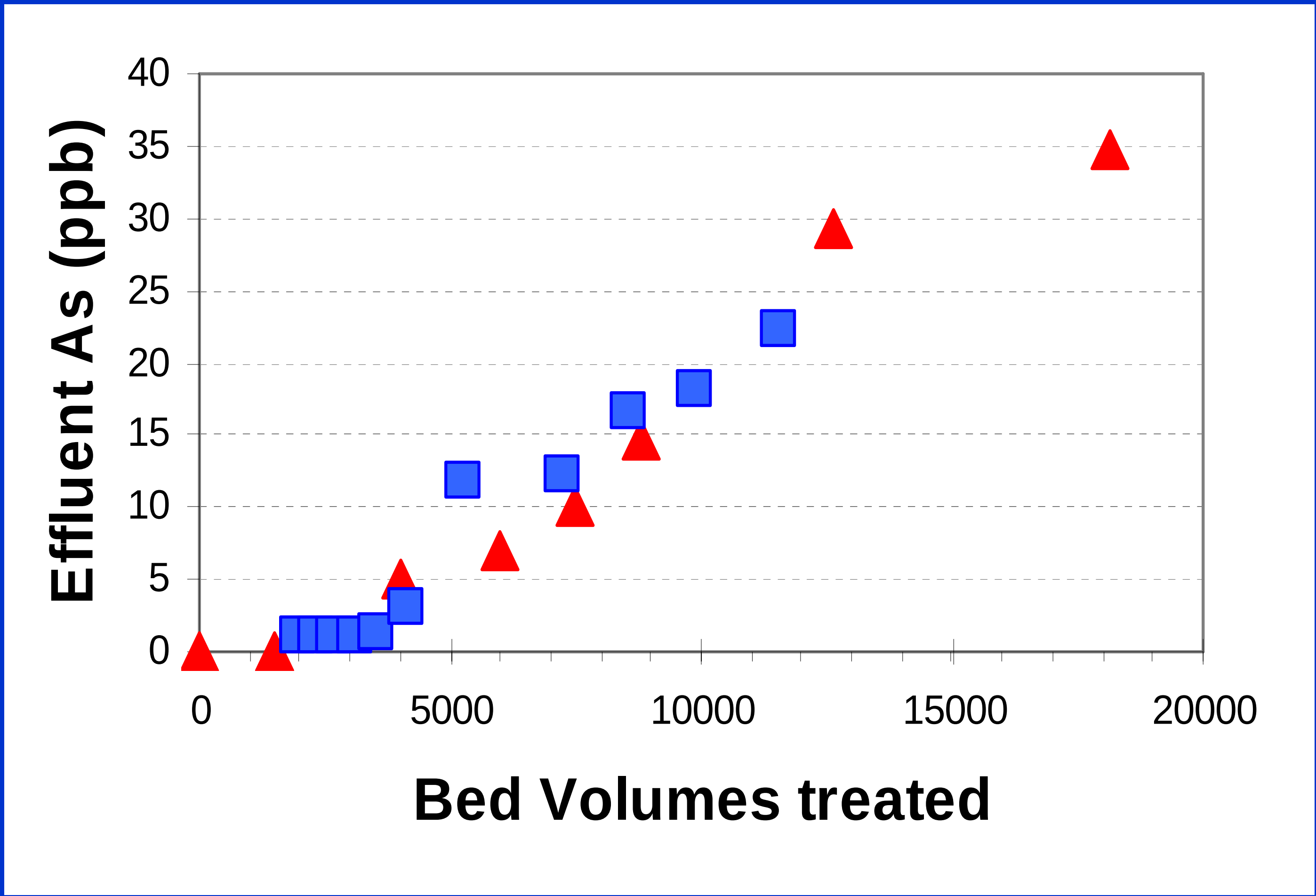
RSSCT-PD vs Pilot (GFH)



RSSCT-PD vs Pilot (E33)



RSSCT-PD vs Pilot (E33)



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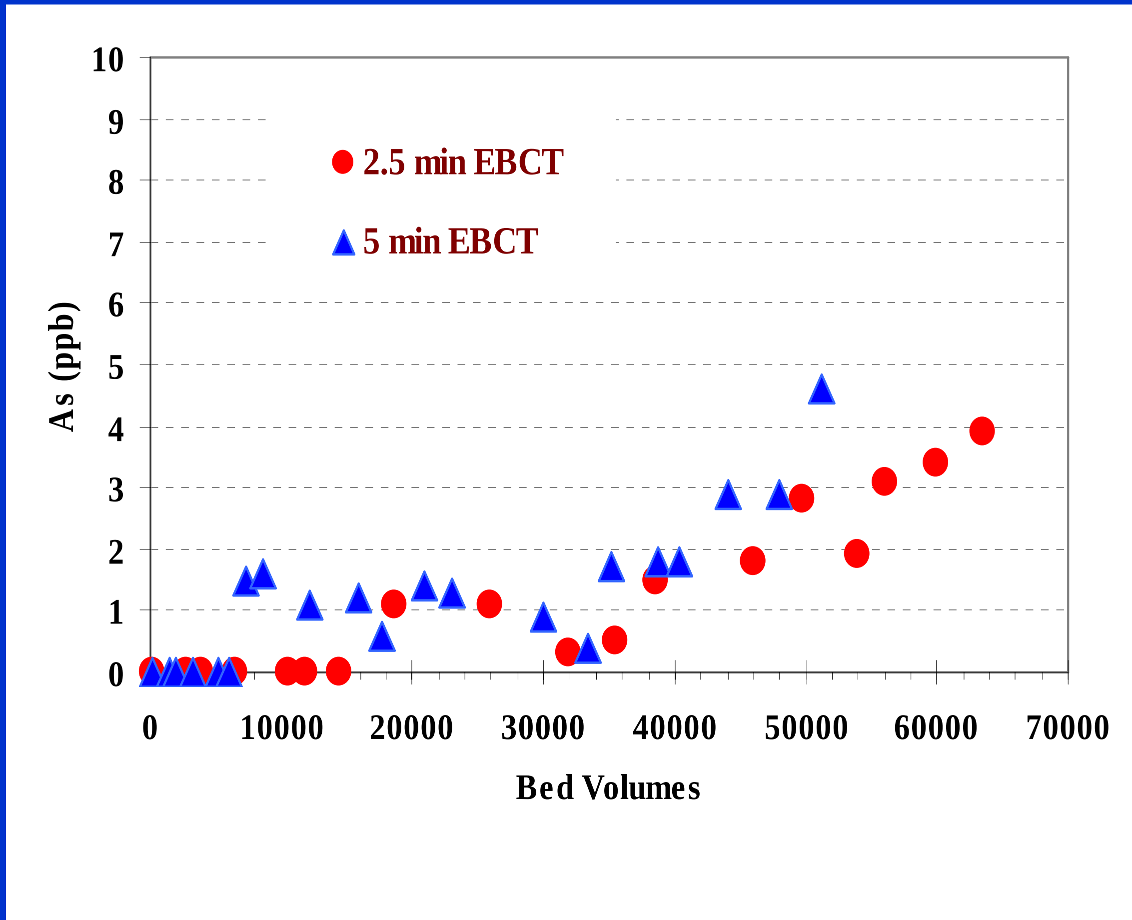
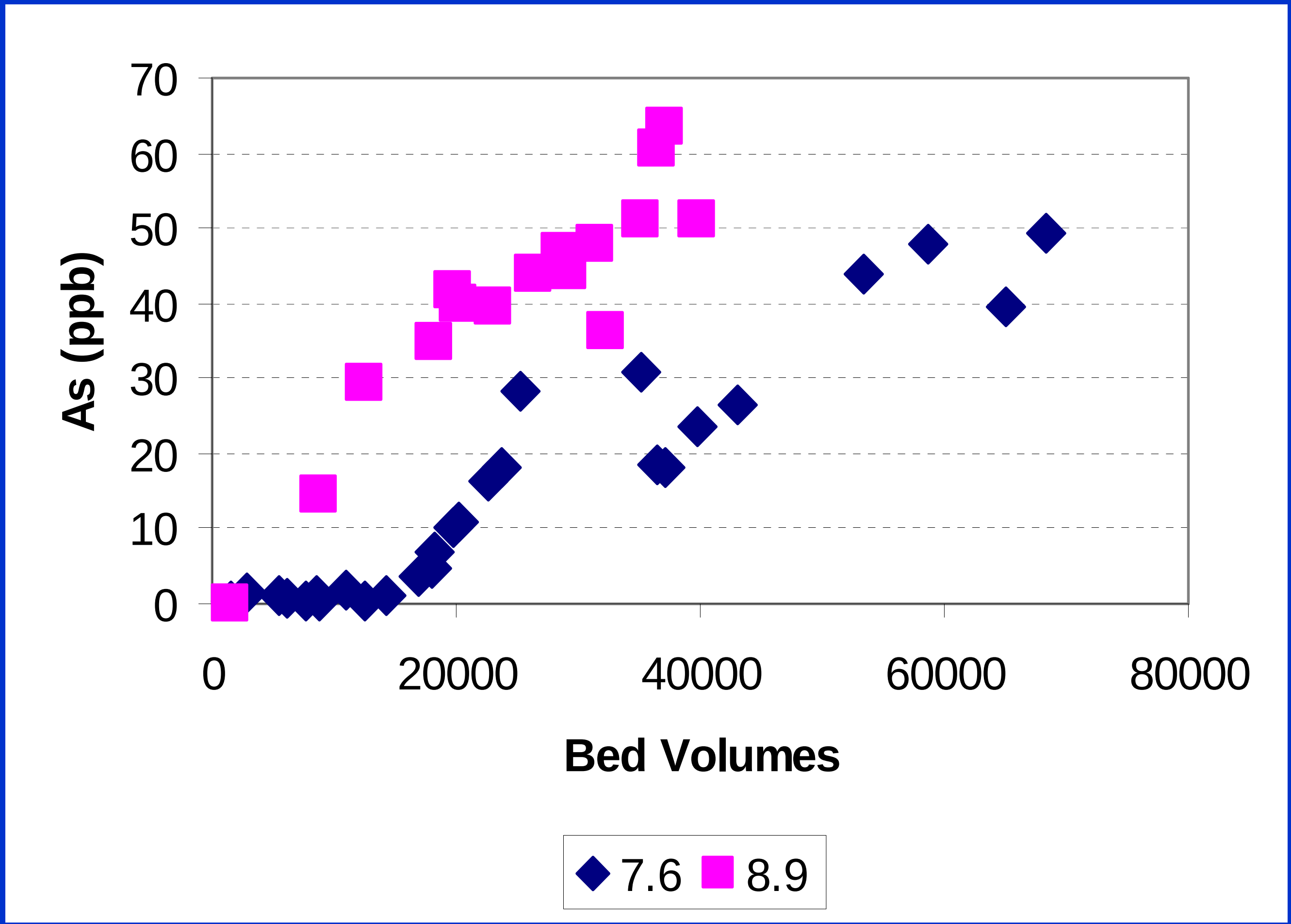
Effect of EBCT (E33)



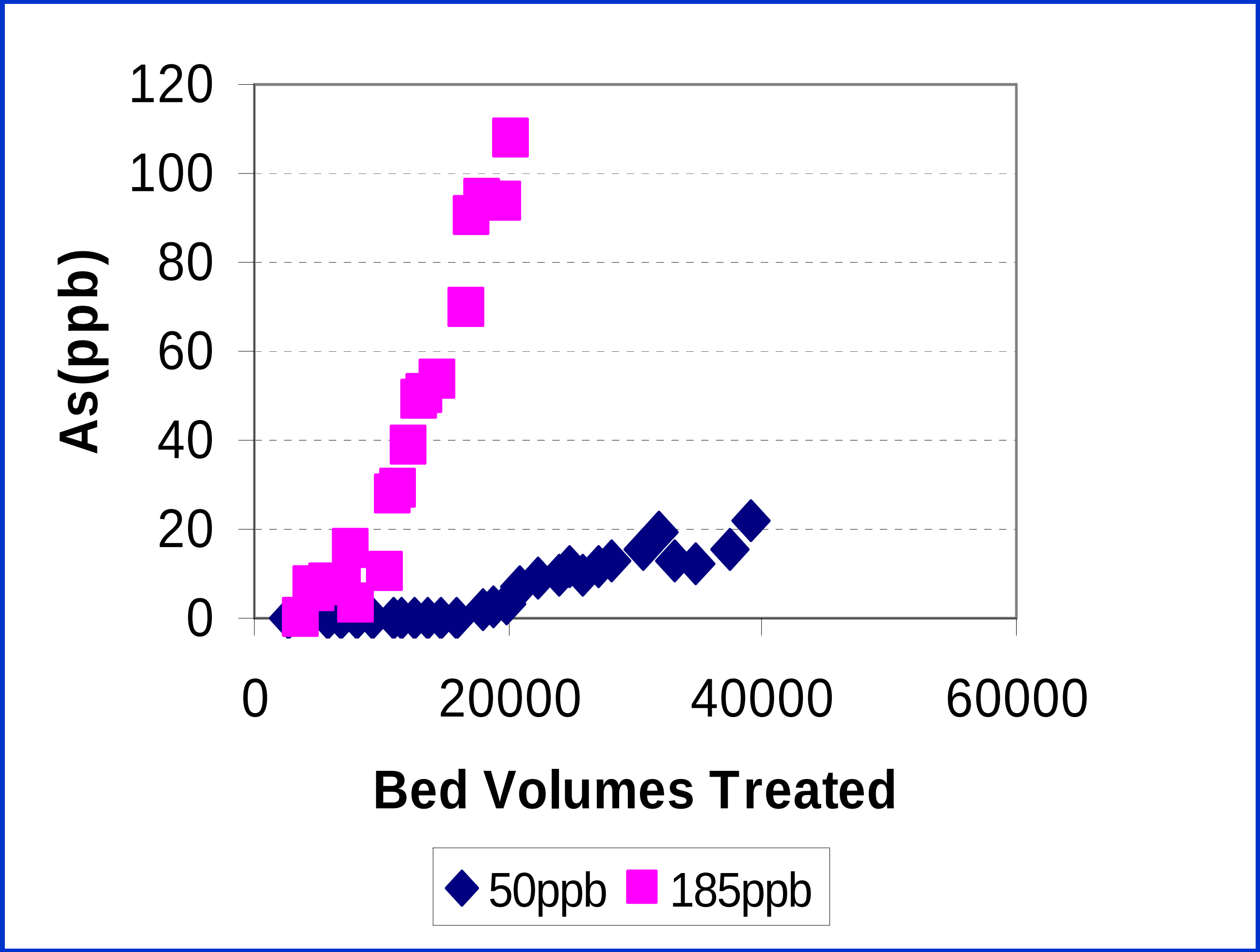
- No Statistical benefits of increasing EBCT 2.5 to 5min

Effect of pH

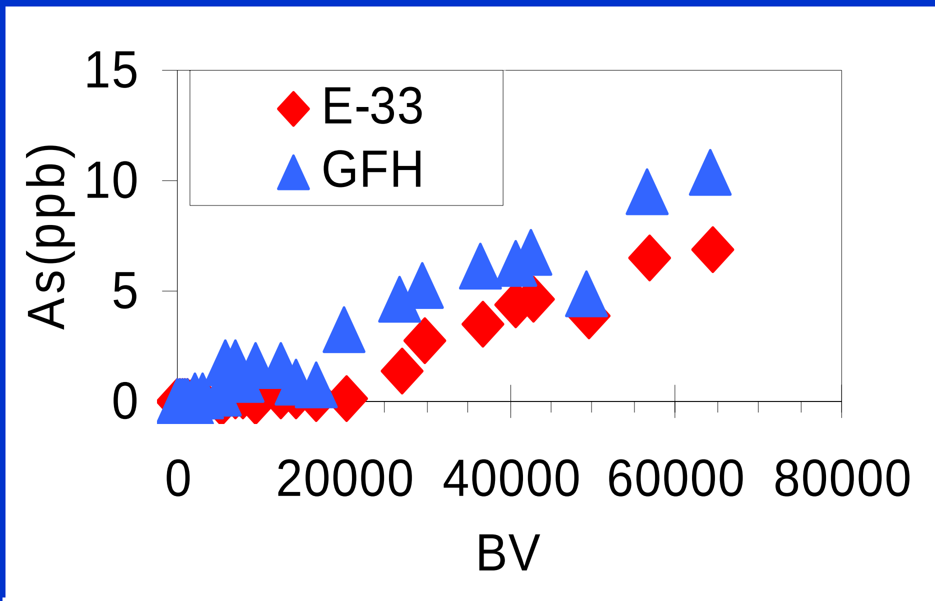


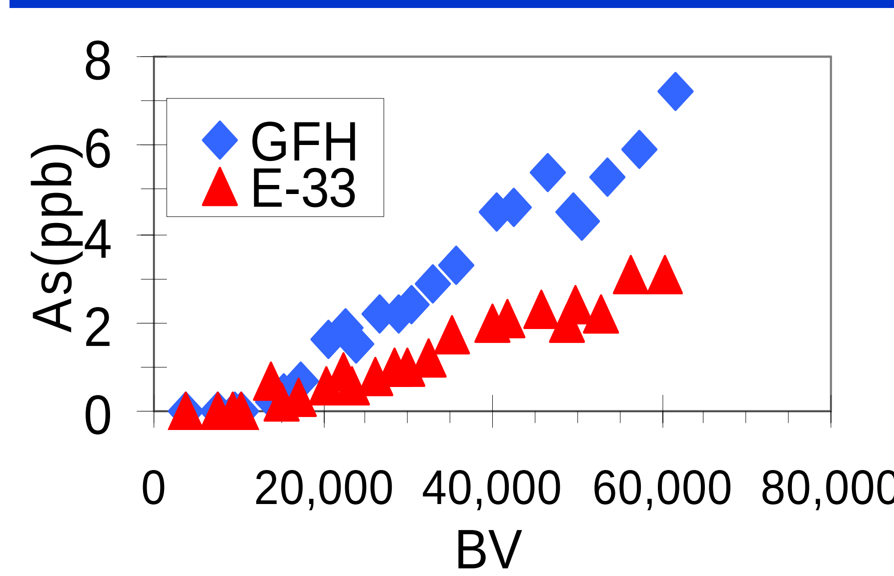
As (ppb)
70
60
50
40
30
20
10
0
0
20000
40000
60000
80000
Bed Volumes
7.6
8.9

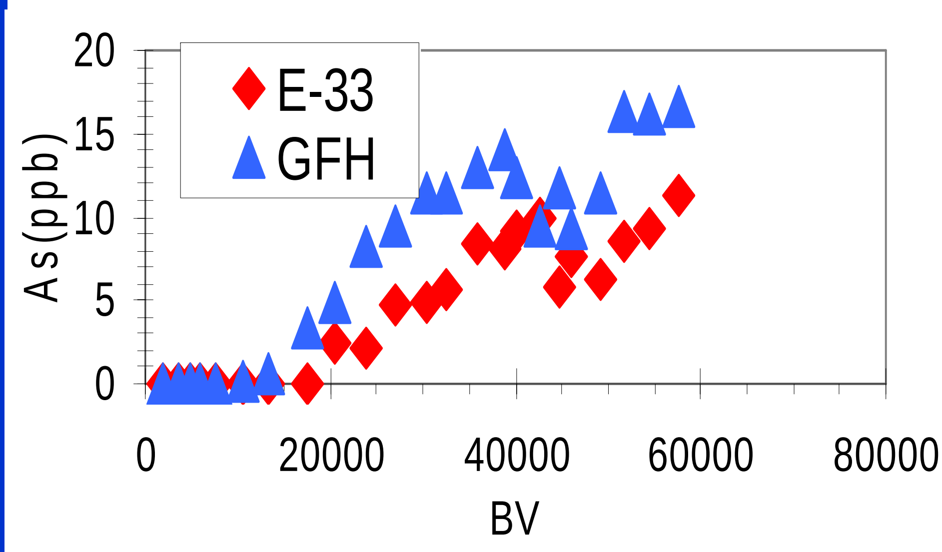
Effect of Initial Arsenate Concentration

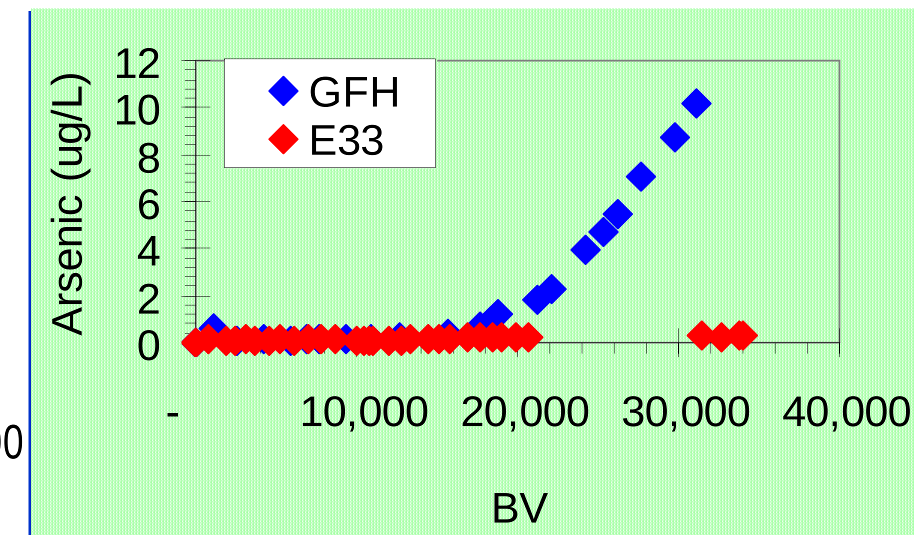


Comparison E33 & GFH

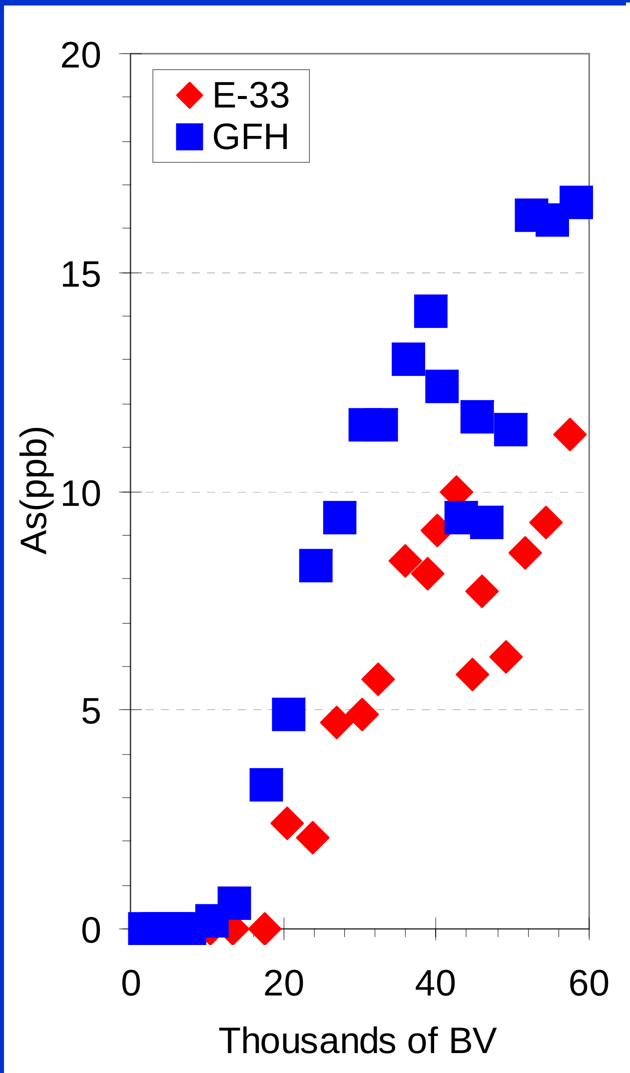


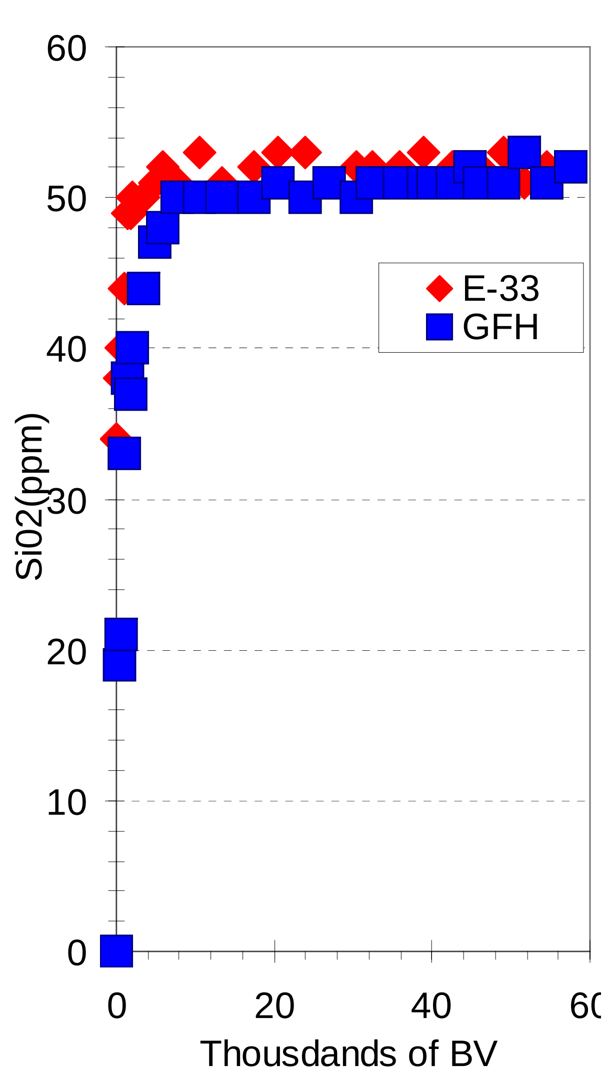


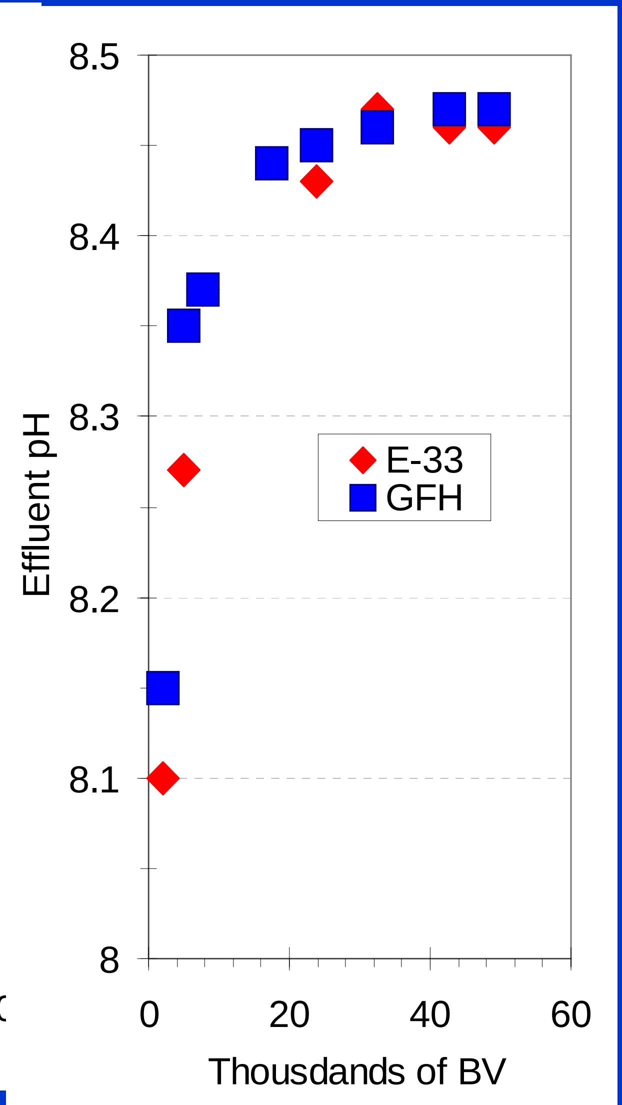




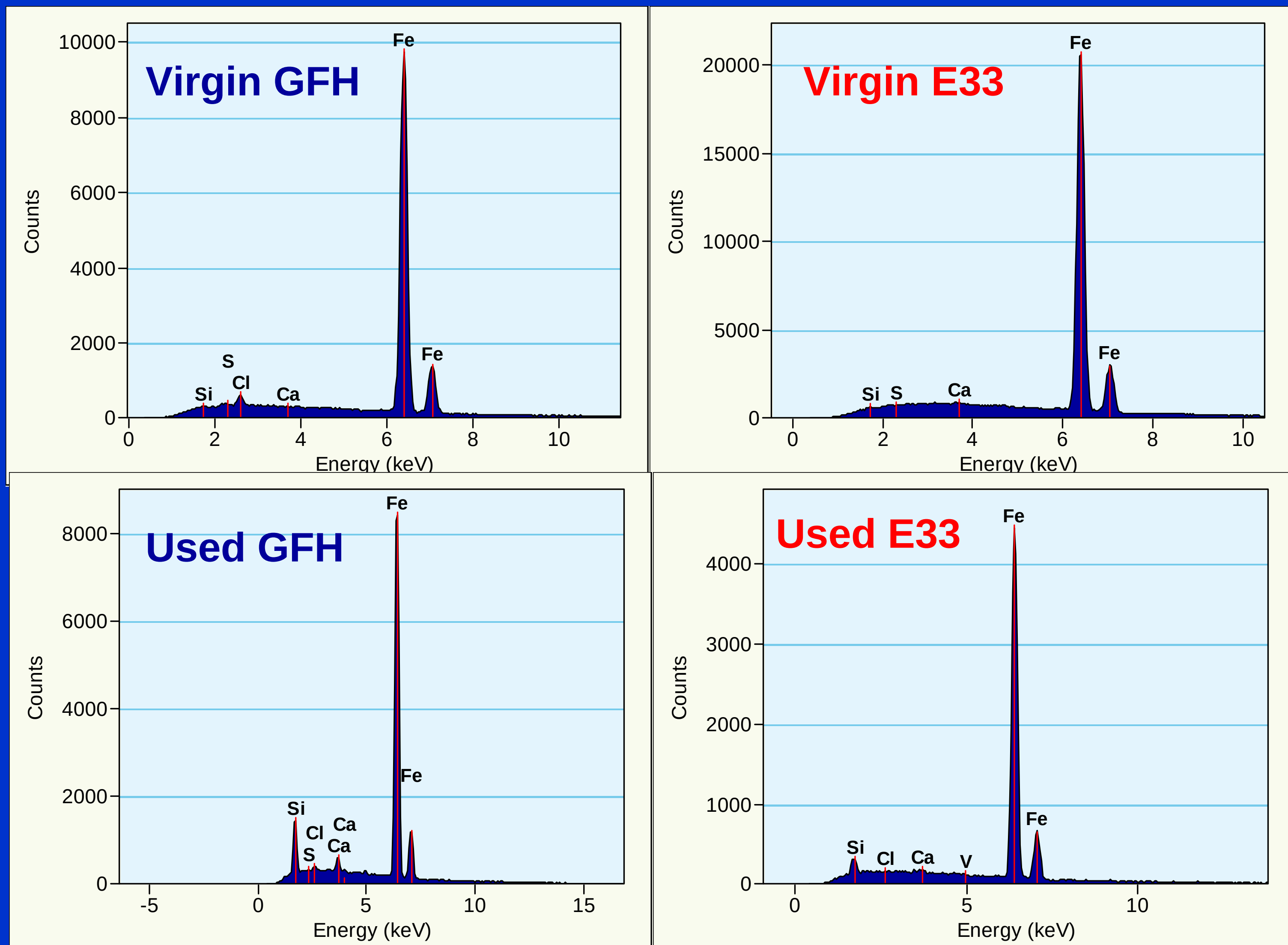
Why difference in Arsenate removal with E33 & GFH



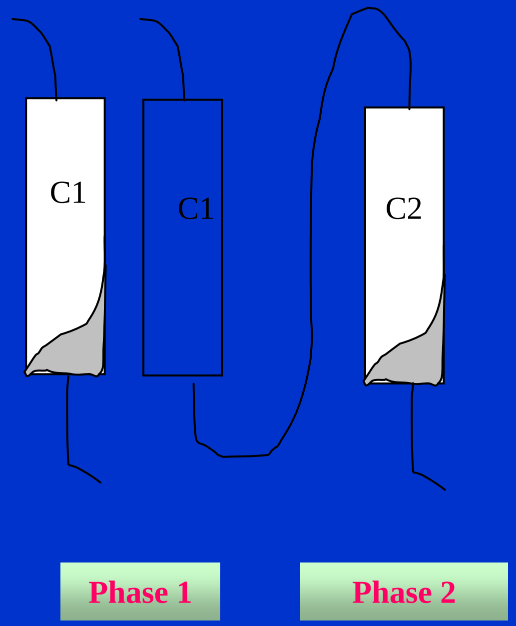




Elemental Surface Composition from SEM with EDX



Series Column Experiments: E33

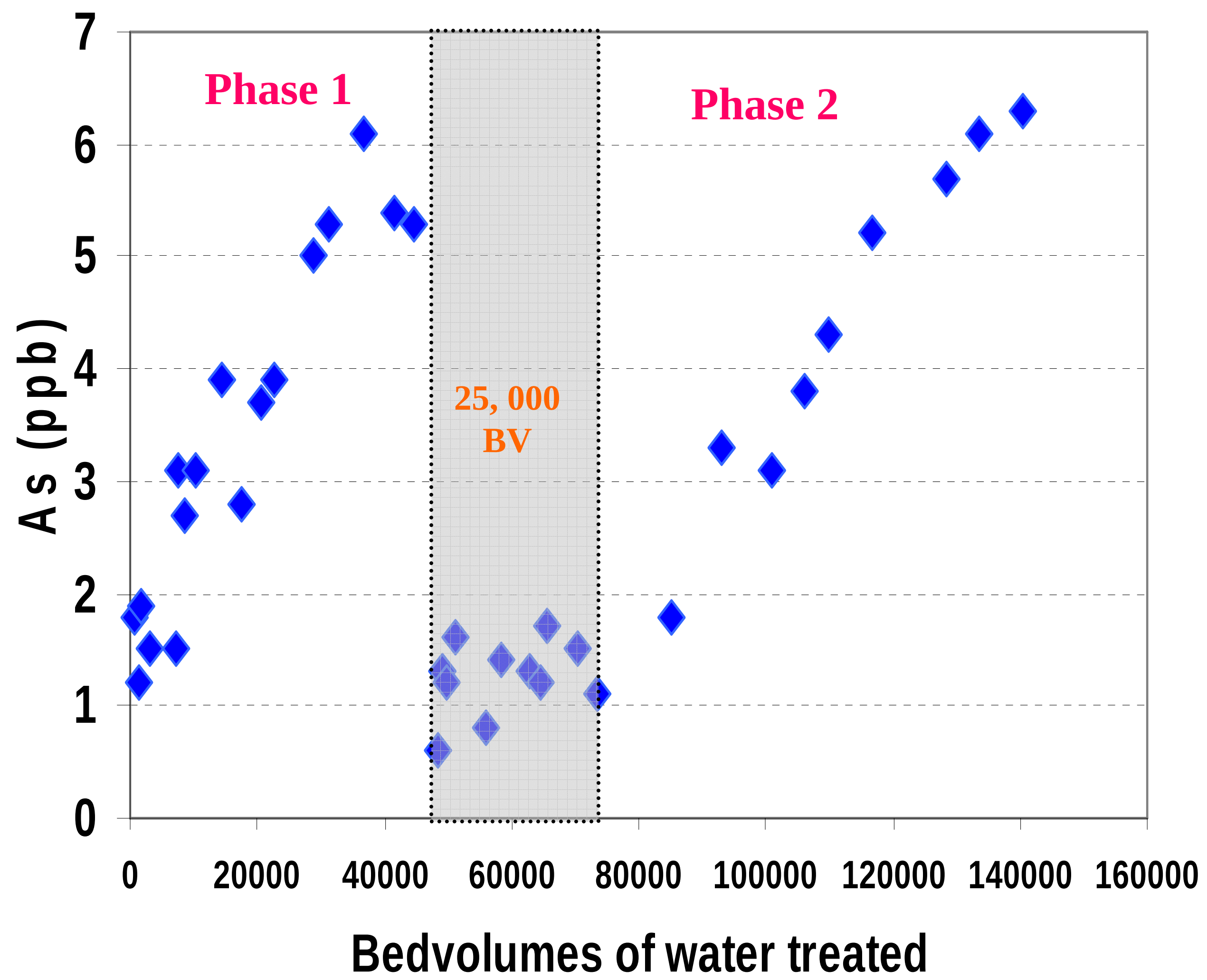


Simulated EBCT:

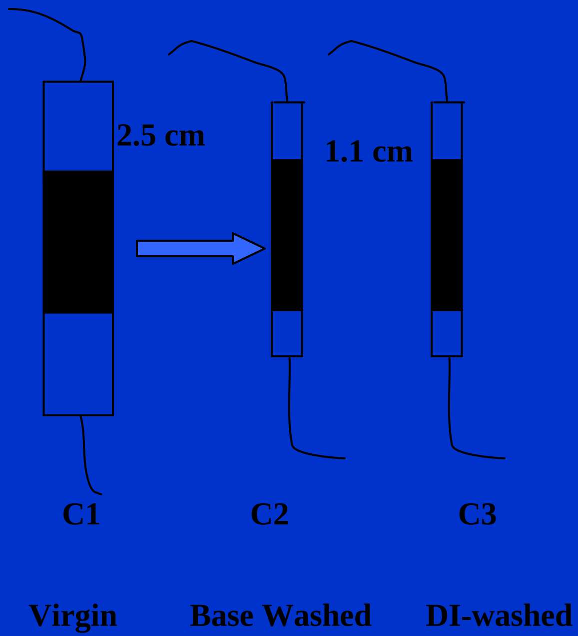
C1 - 2.5 min

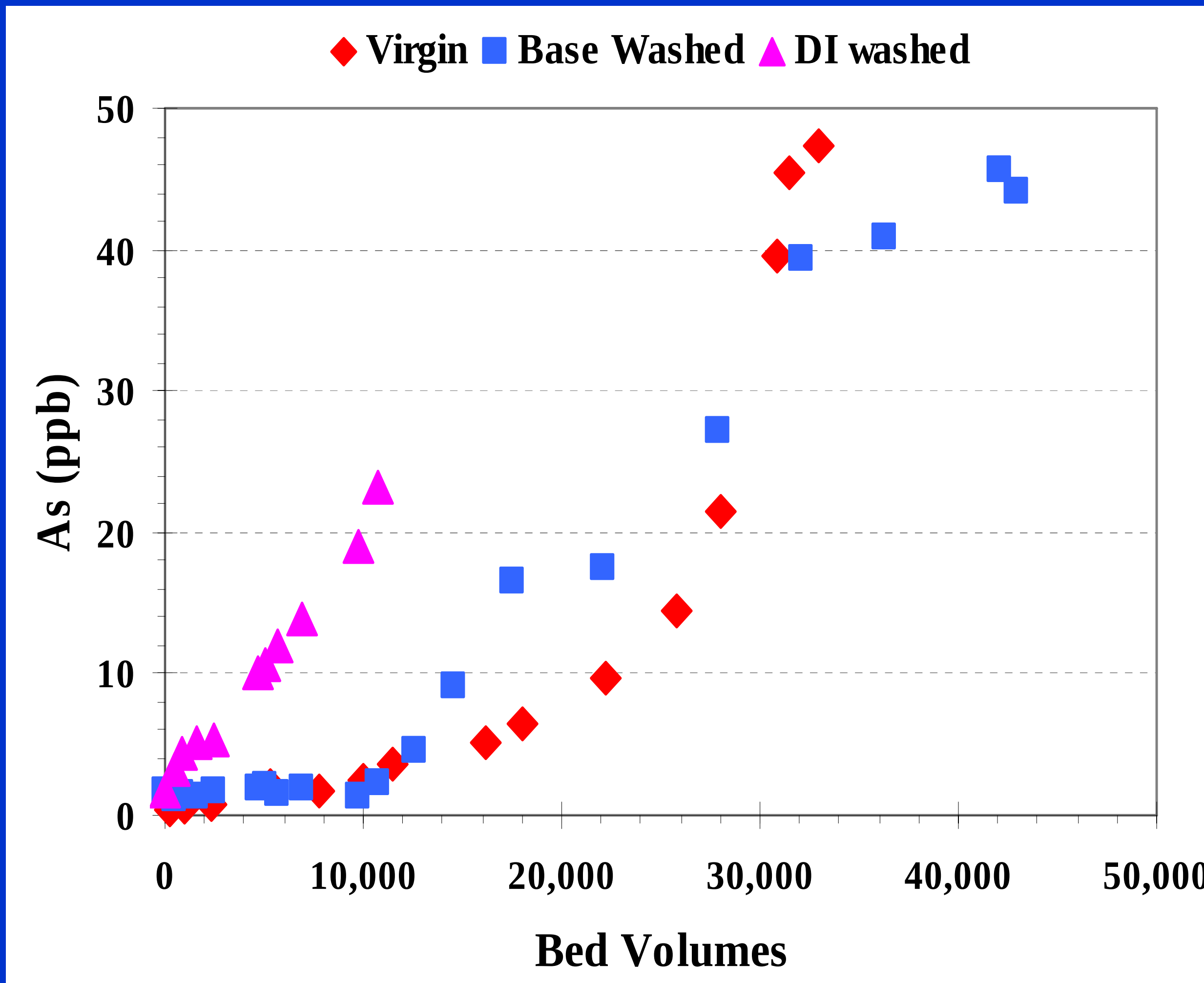
C2 - 2.5 min

C2 was connected when effluent conc. was 5ppb, after 7 days ~ 48,000 BVs



Regeneration of Packed Bed E33





Tap Water Spiked with

As: 50 ppb

Silica : 20 ppb

pH : 8.2

EBCT: C1, C2 and C3 ~ 2.5 min

Summary

- We have recently demonstrated that RSSCTs can be used to evaluate porous arsenic adsorption media (GFH, E33, MetSorbG, Fe-AA, AA, FerriSorb)
- ASU is currently comparing FS-AA, GFH, and E33 against USEPA demonstration facilities at 4 sites
- RSSCTs can facilitate media selection and optimization or effect of water quality
- RSSCTs can facilitate evaluation of packed-bed operational modes (parallel vs series)
- We have run RSSCTs continuously, but many full-scale systems operate intermittently or in cyclic patterns; RSSCTs give a "conservative" breakthrough curve and actual performance using non-continuous operation would be greater than predicted by RSSCTs
- Media performance is a combination of Adsorption <u>Capacity</u> and Adsorption <u>Kinetics</u>

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Table 1 – RSSCT Scaling Equations. Empty bed contact time (EBCT), media diameter (dp), run duration (t), loading rate (V), effective surface diffusivity (D), Reynolds number (Re), Schmidt number (Sc), liquid density (ρL), viscosity (μ), and liquid diffusivity of arsenic (DL). Subscript "SC" indicates small column (i.e., RSSCT column) and "LC" indicates large column (i.e., pilot column). "X" is a variable defined in equation 3 After (Crittenden et al. 1986; Crittenden et al. 1987; Crittenden et al. 1991).

Scaling Assumption	CD or PD Specific Relationships	General Relationships
Constant Diffusivity (CD: X=0)	$\frac{EBCT_{SC}}{EBCT_{LC}} = \left[\frac{d_{p,SC}}{d_{p,LC}}\right]^{2-X} = \frac{t_{SC}}{t_{LC}}$ **Eqn 1** $\frac{V_{SC}}{V_{LC}} = \left[\frac{d_{p,SC}}{d_{p,LC}}\right]$ **Eqn 2**	$\frac{V_{SC}}{V_{LC}} = \left[\frac{d_{p,SC}}{d_{p,LC}}\right] \times \frac{\mathrm{Re}_{SC} \times Sc}{\mathrm{Re}_{LC} \times Sc}$ **Eqn 5** $\mathrm{Re} = \frac{V \times \rho_L \times d_p}{\mu}$ **Eqn 6** $Sc = \frac{\mu}{D_L \times \rho_L}$ **Eqn 7**
Proportional Diffusivity (PD; X=1)	$\frac{D_{SC}}{D_{LC}} = \left[\frac{d_{p,SC}}{d_{p,LC}}\right]^{X}$ **Eqn 3** $\frac{EBCT_{SC}}{EBCT_{LC}} = \left[\frac{d_{p,SC}}{d_{p,LC}}\right] = \frac{t_{SC}}{t_{LC}}$ **Eqn 4**	

Intermittent Column Operation