Lead and Tin Transport and Retention in Soils: Miscible Displacement and Modeling

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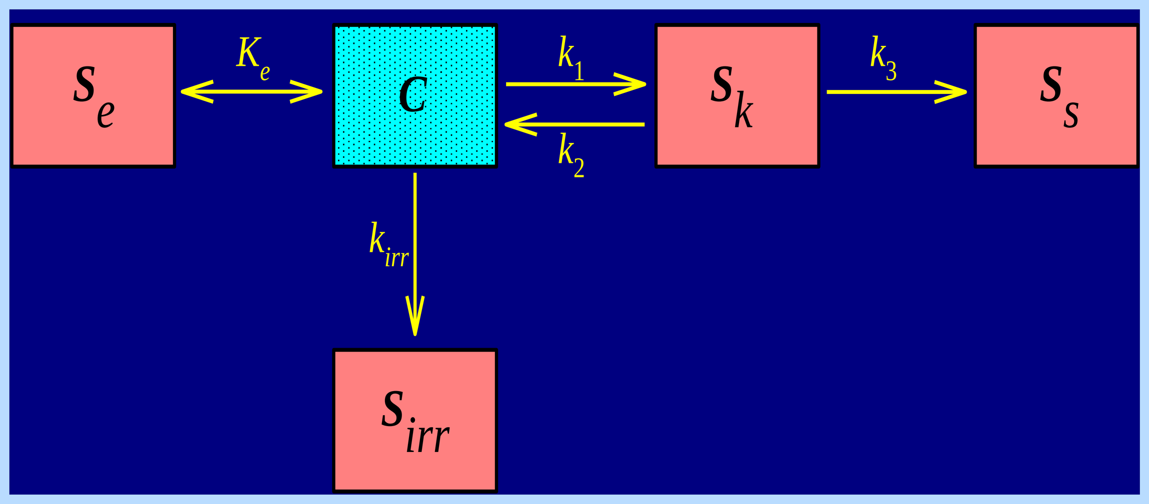
ABSTRACT

Sorption batch and miscible displacement column experiments were carried out to assess the mobility and reactivity of tin (Sn) and lead (Pb) in soils. Two soils were used, an Olivier soil (fine-silty, mixed, active, thermic Aquic Fraglossudalfs) and a Windsor soil (mixed, mesic Typic Udipsamments). Isotherm results exhibited highly nonlinear sorption for both heavy metals. Lead isotherms indicated a Freundlich exponent parameter n of 0.204 and 0.249 for Windsor and Olivier soils, respectively. The respective values for Sn were greater than 1 (2.46 and 3.72) which implies irreversible sorption. For the transport experiments, input solutions of Sn and Pb were introduced in consecutive pulses into each soil column. For both soils, measured effluent concentrations indicated extremely limited mobility of Sn where > 99% of Sn applied was retained in each soil column. In contrast, breakthrough results for Pb exhibited extensive mobility in both soils. For Olivier soil, Pb recovery in the effluent solution was 57.6% and 96.4%, for the Sn-Pb and Pb-Sn pulse sequences, respectively. For Windsor soil, the respective Pb recoveries were 37.4% and 52%. Furthermore, the presence of Sn resulted in enhanced mobility of Pb for both soils. A second-order two-site model (SOTS) was successful in describing Pb transport in both soils and a reference sand column.

❑ OBJECTIVES

- ❑ To quantify the sorption and transport of Sn and Pb in soils
- ❑ To assess the competitive reactivities of Sn and Pb on their mobility and retention in soils.

SECOND-ORDER, TWO-SITE TRANSPORT MODEL (SOTS)



$$S_e = K_e \theta C \emptyset$$

$$\frac{\partial S_{irr}}{\partial t} = k_{irr} S_{irr}$$

$$\frac{\partial S_k}{\partial t} = k_1 \theta C \emptyset - (k_2 + k_3) S_k$$

$$\frac{\partial S_s}{\partial t} = k_3 S_k$$

$$S_{max} = \emptyset + S_e + S_k + S_s + S_{irr}$$

$$\theta \frac{\partial C}{\partial t} + \frac{\partial S}{\partial t} = \frac{\partial}{\partial x}\left(D\theta \frac{\partial C}{\partial x}\right) - q \frac{\partial C}{\partial x}$$

where C is the solute in the solution phase, S_e is the amount retained on equilibrium-type sites, Ø is the number of sites that are available for solute adsorption in soils, S_k is the amount retained on kinetic-type sites, S_s is the amount retained irreversibly by consecutive reaction, S_{irr} is the amount retained irreversibly by concurrent type of reaction, and K_e, k_1, k_2, k_3, and k_{irr} are reaction rates. D is the hydrodynamic dispersion ($cm^2\ h^{-1}$), q is Darcy's water flux density ($cm\ h^{-1}$), and x is the vertical distance (cm).

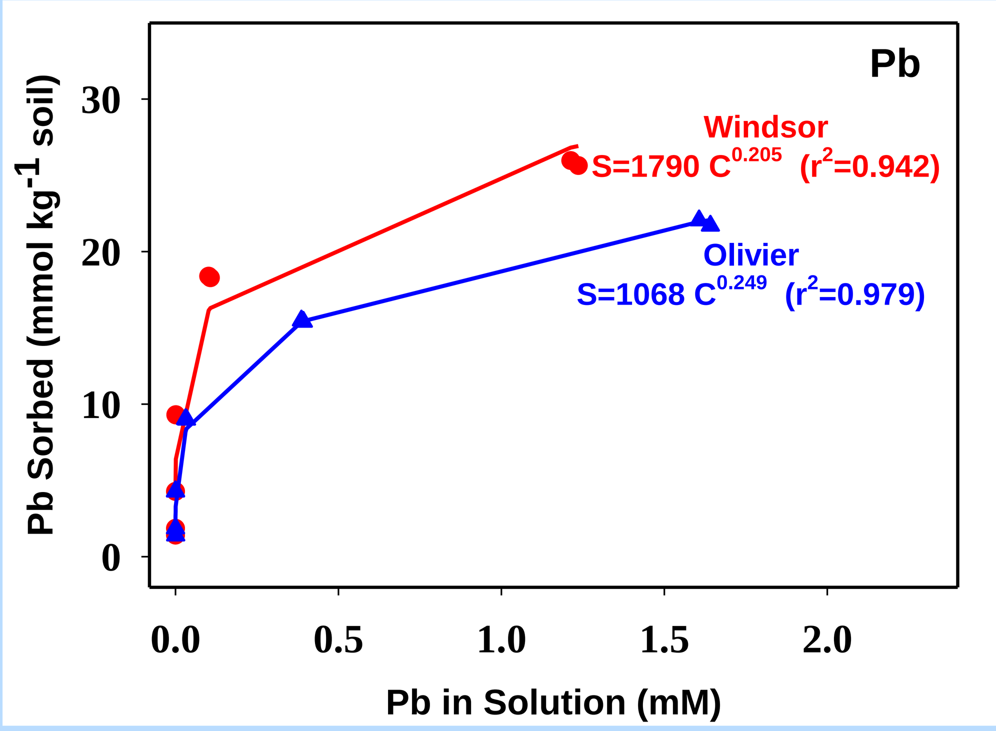


Fig. 1. Lead sorption isotherms for Windsor and Olivier soils. Solid curves are Freundlich model calculations.

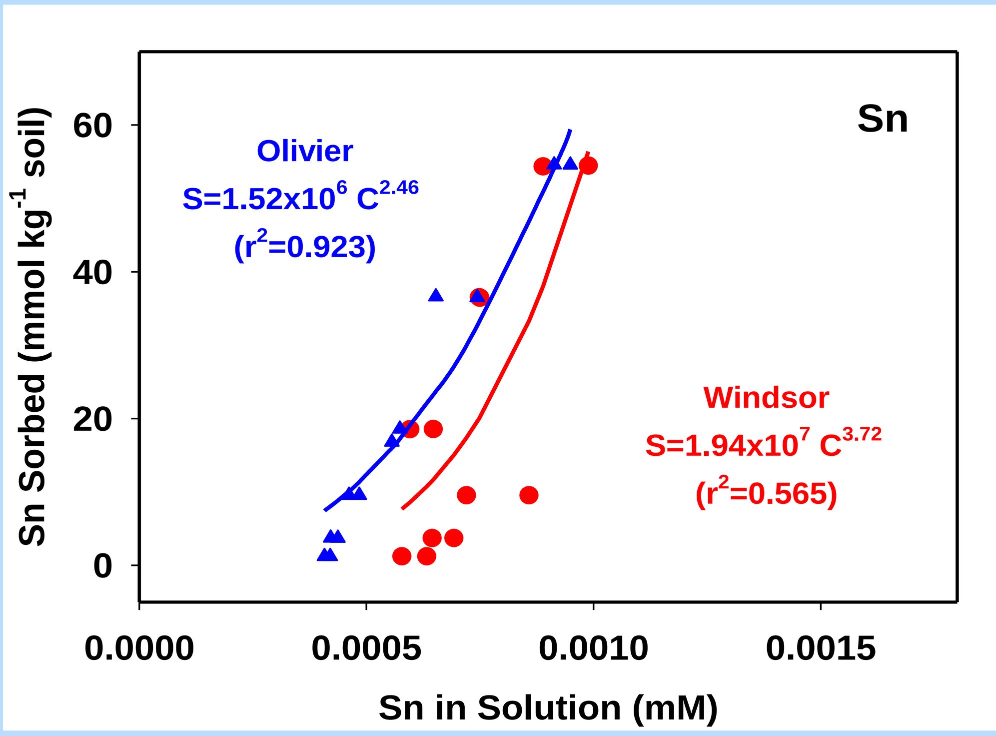


Fig. 2. Tin sorption isotherms for Windsor and Olivier soils. Solid curves are Freundlich model calculations.

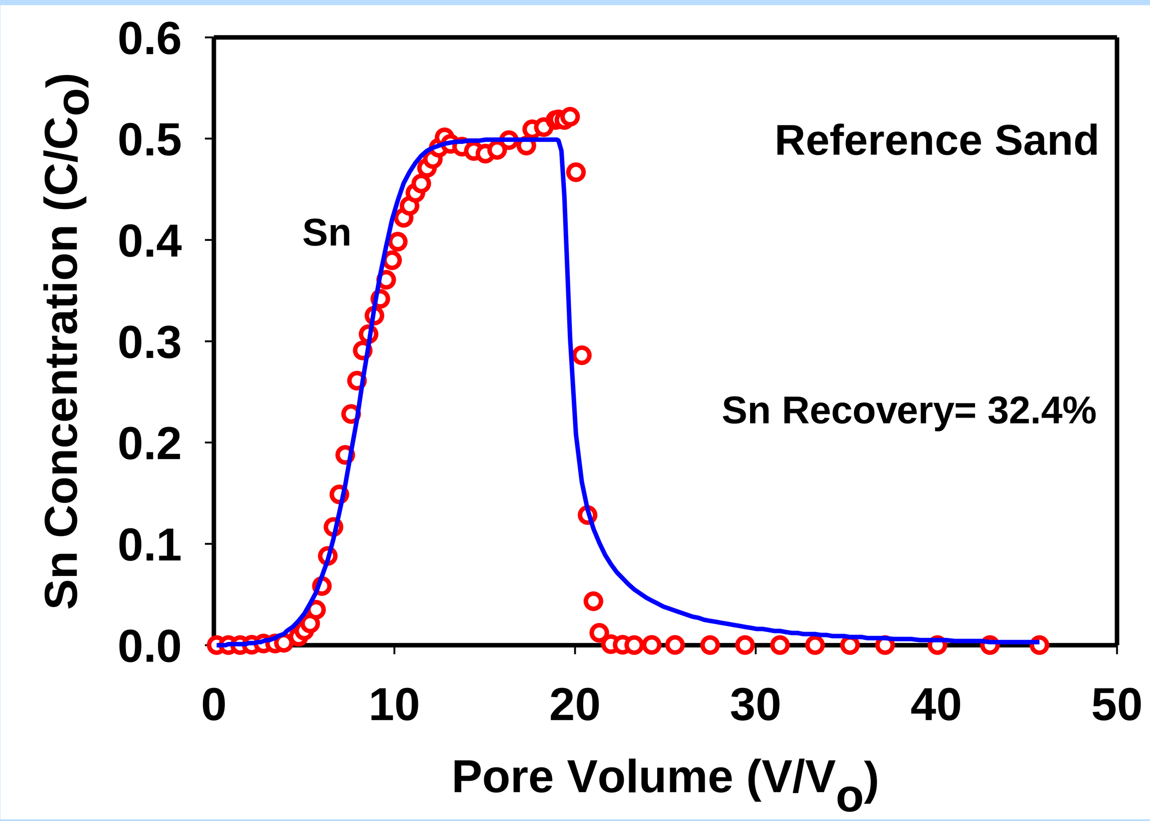


Fig. 3. Breakthrough results of Sn from the reference sand. Solid curve is SOTS model simulation.

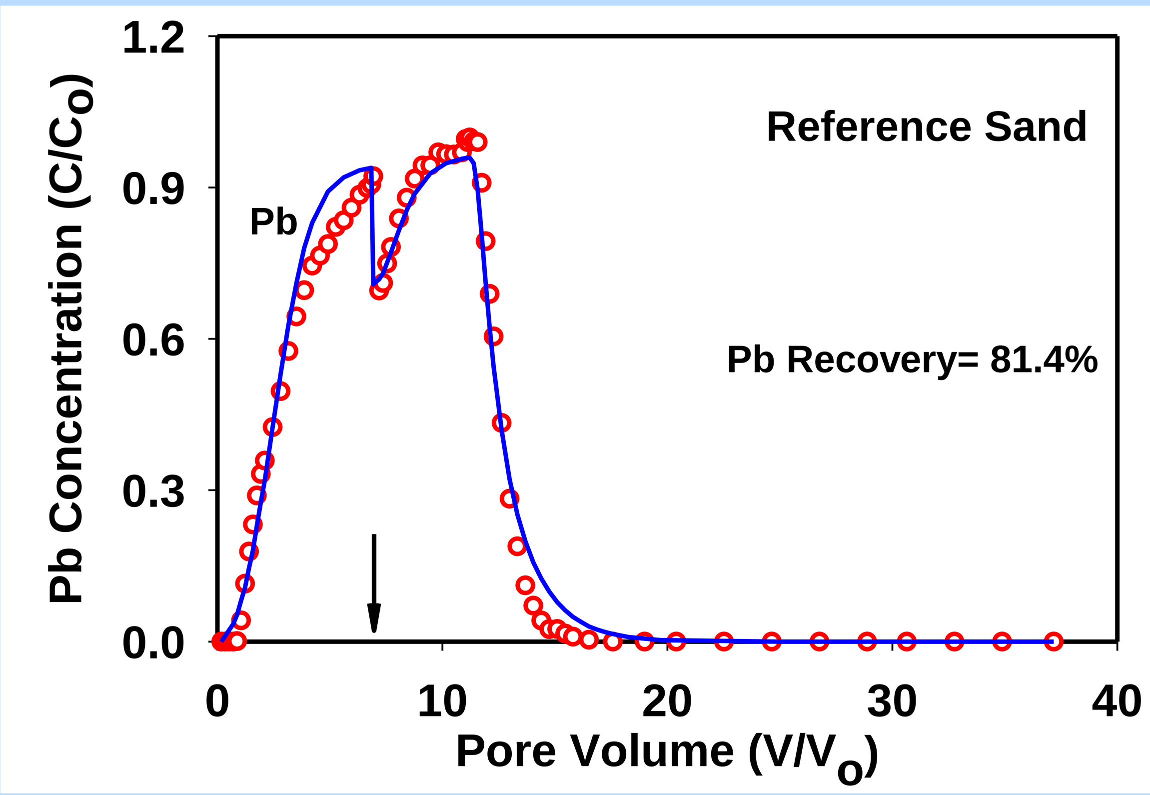


Fig. 4. Breakthrough results of Pb from the reference sand; the arrow indicates when flow interruption occurred. The solid curve is SOTS model simulation.

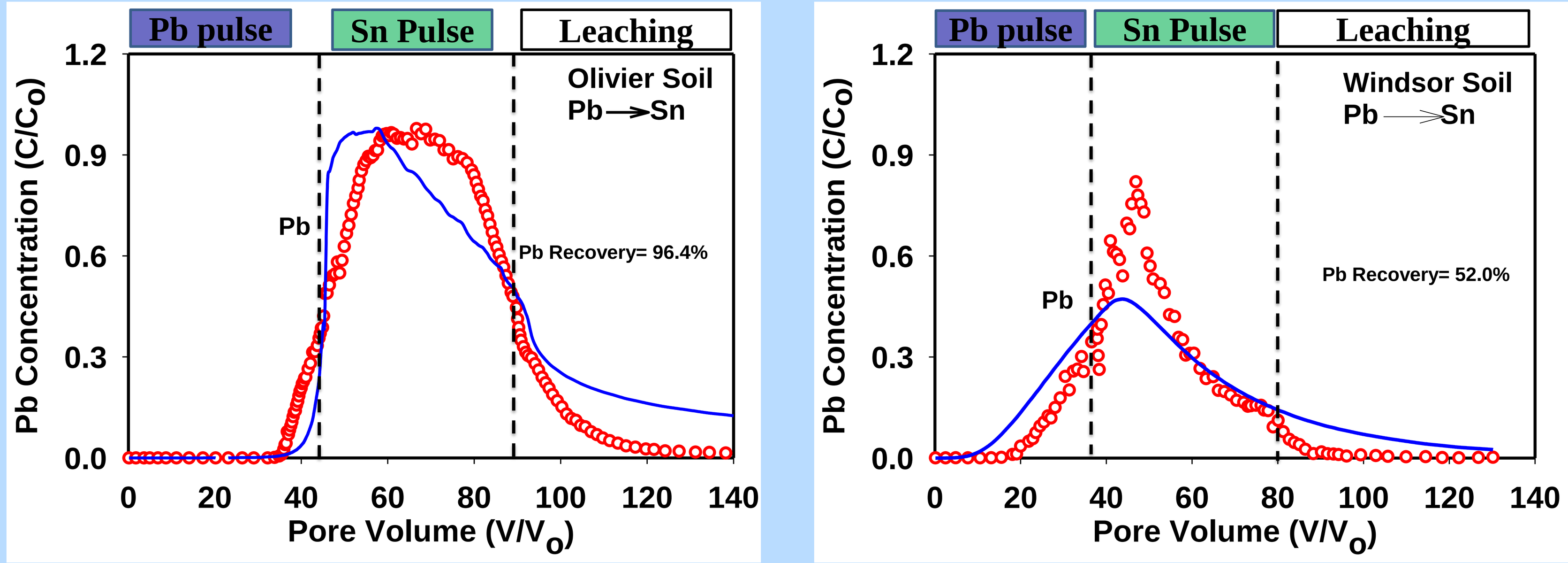


Fig. 5. Breakthrough results of Pb from Olivier soil (left) and Windsor soil (right) where Pb - Sn pulses sequence were applied . The solid curve is SOTS model simulation.

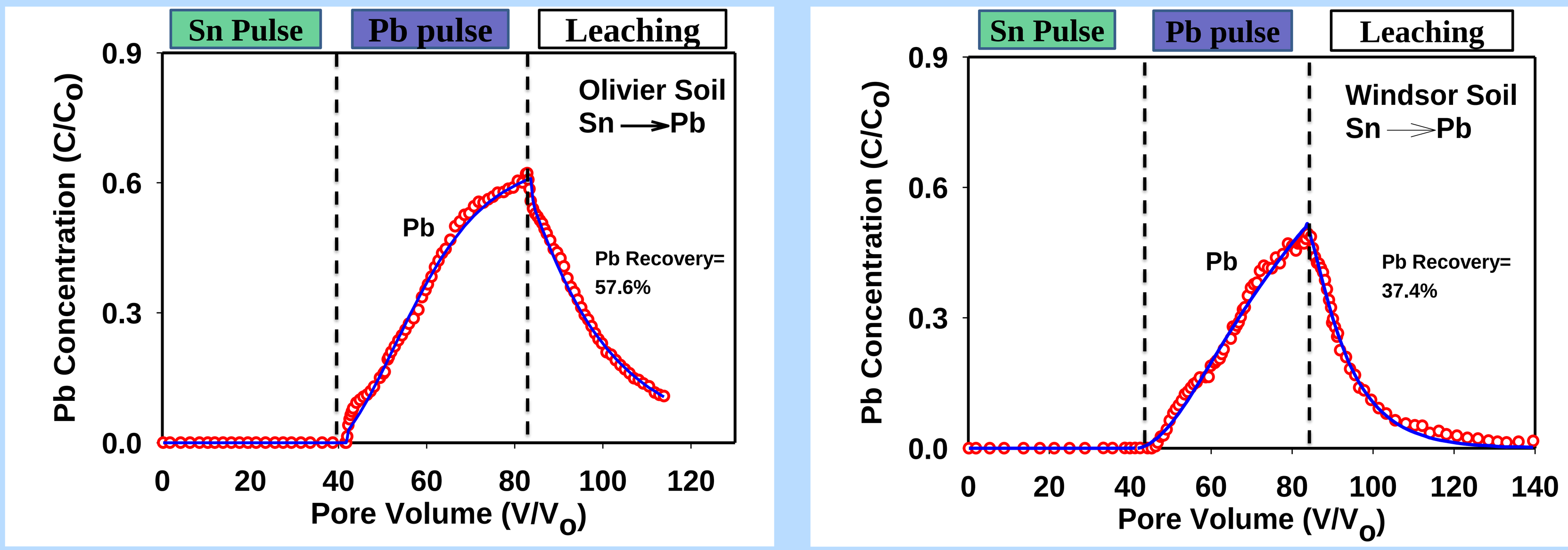


Fig. 6. Breakthrough results of Pb from Olivier (left) and Windsor (right) soils where Sn- Pb pulses sequence were applied . The solid curve is SOTS model simulation.

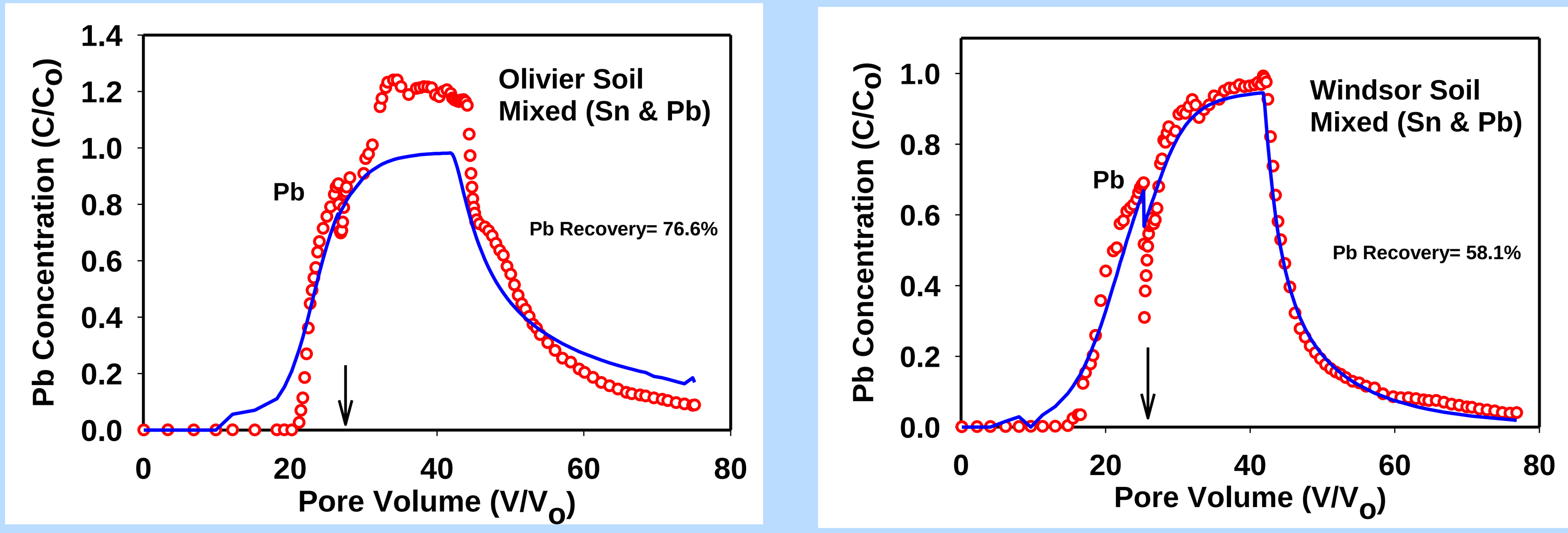


Fig. 7. Breakthrough results of Pb from Olivier (left) and Windsor (right) soils where pulses of mixed Sn and Pb were applied ; the arrow indicates when flow interruption occurred. The solid curve is SOTS model simulation.

CONCLUSIONS

❑Sorption isotherms of Sn and Pb were nonlinear where Pb exhibited lower affinity compared to Sn. For both soils, the shape of Sn isotherms indicated possible irreversible sorption.

❑Incomplete recovery of Pb (81.4%) and Sn (32.4%) compared to amount added to reference sand columns.

❑The presence of Sn resulted in enhanced mobility of Pb for both soils as evidenced by early arrival of Pb in the effluent.

❑The second-order two-site model (SOTS) successfully described Pb mobility in both soils as well as Pb and Sn in the reference columns.