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Application of multirate mass transfer model to radionuclide transport in Culebra Dolomite core

Bwalya Malama, PhD, and Moo Lee, PhD

[1]Sandia National Laboratories, Carlsbad, NM

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Outline

- What is the multirate model?
- Culebra transport
- Core-scale experiments
- Analysis of breakthrough data
- Concluding remarks

Multirate transport model

- Multiple types & scales of porosity
- Mobile-immobile domain mass exchange
- Long tailing & early breakthrough
- Dual-porosity model inadequate
  - Rate constant is deterministic
- Need multiple rates of mass exchange
  - Rate constant is random variable

Mathematical Formulation

- Mobile domain transport:

$$\frac{\partial c}{\partial t} + \beta_T \int_0^\infty p(\omega) \frac{\partial c_{\mathrm{im}}}{\partial t} \mathrm{d}\omega = D_R \frac{\partial^2 c}{\partial x^2} - v_R \frac{\partial c}{\partial x}$$

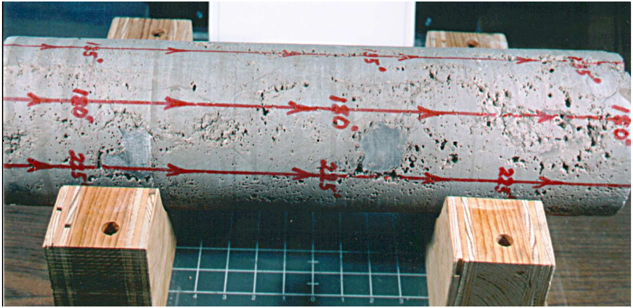
- Immobile domain transport:

$$\frac{\partial c_{\mathrm{im}}}{\partial t} = \omega \left(c - c_{\mathrm{im}} \right)$$

- $p(\omega)$ is distribution function of ω

(After Haggerty & Gorelick, 1995)

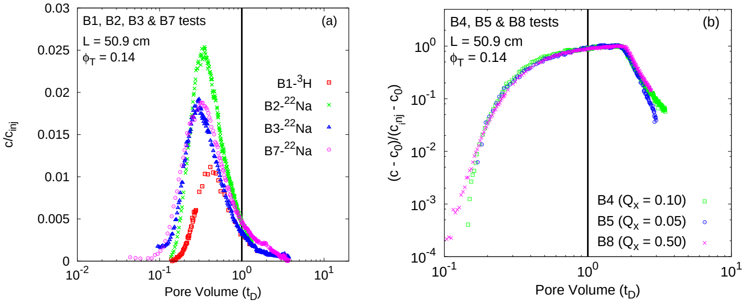
Culebra transport



- Culebra is most transmissive saturated unit above repository
- Modeled with dual-porosity model in PA
- Field scale tracer tests suggest multirate model (see Haggerty et al., 2001; Meigs & Beauheim, 2001)

Culebra core experiments

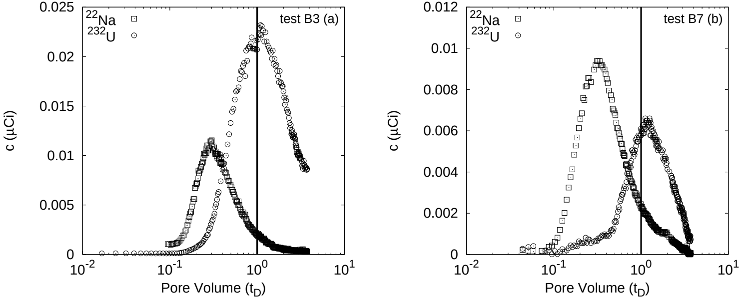
- Described in Lucero et al. (1998)
- Conservative tracers tritium & sodium-22
- Non-ideal breakthrough behavior



- Analyzed with single- & dual-porosity models
  - Poor fit to data (esp. in log-log scale)

Culebra core experiments

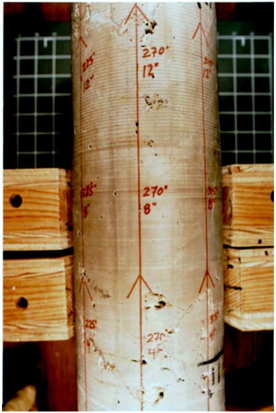
- Uranium-232 transport
- Sorbing solute

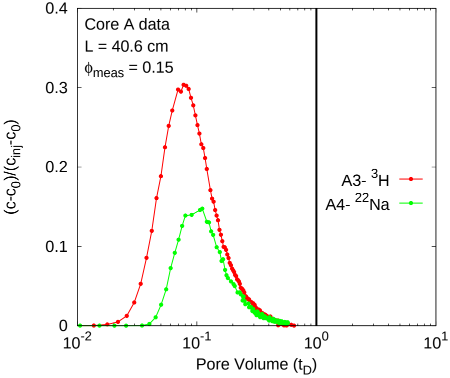


- Late breakthrough relative to sodium-22

Analysis with multirate model
Data from core-A

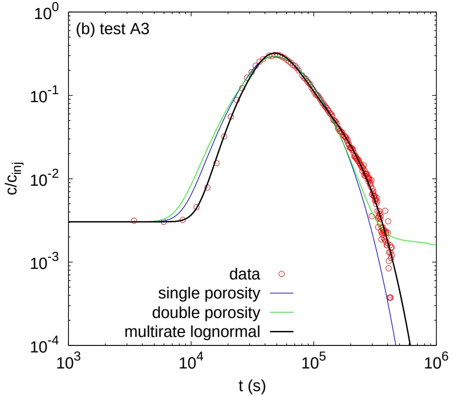
- D = 14.5 cm; L = 40.6 cm; Q = 0.1 mL/min





Analysis with multirate model
Model fits to data

- Obtained with PEST
- Minimized sum of squared residuals
- Estimated $\{\phi_{\mathrm{m}}, \alpha_L, \mu, \sigma, t_{\mathrm{inj}}\}$



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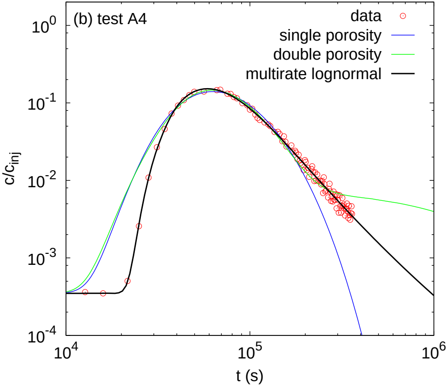

Table: Parameter estimates from conservative tracer experiments.

Test	Model	ϕ_m	α_L (cm)	ω_D	μ	σ	t_{inj} (hrs)
A3 ^{3}H	Single	0.013	12.2				6.43
	Double	0.013	14.9	0.017			7.87
	Multirate	0.011	6.28	3.78	1.33	0.012	6.68
A4 ^{22}Na	Single	0.018	6.80				3.48
	Double	0.019	7.92	0.086			6.02
	Multirate	0.007	0.23	1.14	0.129	10.2	3.95

Remarks

- Multirate model yields improved fits to core-scale data
- Results confirm those obtained at field scale
- Transport in Culebra presently modeled with dual-porosity model (deterministic rate constant)
- Numerical codes need modification to incorporate multirate model
- Code modification underway