現地入滲追蹤劑試驗推估土壤傳輸參數

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Introduction
• Groundwater and soil problem cause health risk. Fate and transport models to calculate chemical transport in soils are increasingly being used in practice.

• Mathematical model of solute transport is usually described by Advection-Dispersion Equation (ADE).

• Mathematical modeling needs to know the values of solute transport parameters, including the longitudinal dispersion coefficient and the transverse dispersion coefficient.
Advection

- 平均的污染物移動行爲

实际速度在孔隙中
平均速度

\[ L_{AB} \]

\[ V_{A \to B} \]

\[ h_A \]

\[ h_A \]
Mechanical dispersion

<table>
<thead>
<tr>
<th>Pore size</th>
<th>Path length</th>
<th>Friction in pore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow</td>
<td>Fast</td>
<td>Slow</td>
</tr>
<tr>
<td>Fast</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Long path</td>
<td>Short path</td>
<td>Slow Fast</td>
</tr>
<tr>
<td>Slow</td>
<td>Fast</td>
<td>Slow</td>
</tr>
</tbody>
</table>
longitudinal dispersion, $a_L$

Transverse dispersion, $a_T$

groundwater flow direction
Materials and methods
The apparatus

- Calibrated head tanks
- Flow divider
- Suction cup
- Vacuum pump
- Triple-ring infiltrometer
The test site should be nearly level, or a level surface

Drive the rings into the soil with blows of a heavy sledge to a depth

Install suction cup
Set up the calibrated head tanks (mariotte tubes)

KCI was poured into the internal ring, then soil water samples were taken from the cup samplers

Sample packing and record
Chemical analysis

Analysis:
(1) Filter
(2) Ion Chromatography, IC
Chemical analysis

Ion Chromatography, IC

AG9-HC (Ion Chromatography, IC)

AS9-SC (Anion-Exchange Columns)
Calculating the transport parameters
\[
\frac{\partial C(r, z, t)}{\partial t} = D_L \frac{\partial^2 C(r, z, t)}{\partial z^2} - V \frac{\partial C(r, z, t)}{\partial z} + D_T \left[ \frac{\partial^2 C(r, z, t)}{\partial r^2} + \frac{1}{r} \frac{\partial C(r, z, t)}{\partial r} \right]
\]  
(1)

\textbf{Zhang et al. (2006)}

\[ C(r \to \infty, z, t) = 0 \]  
(2)

\[ VC(r, z = 0, t) - D_L \frac{\partial C(r, z = 0, t)}{\partial z} = \begin{cases} \frac{M}{\varphi \pi R_0^2} \delta(t) & 0 \leq r \leq R_0 \\ 0 & R_0 \leq r \leq \infty \end{cases} \]  
(3)

\[ C(r, z \to \infty, t) = 0 \]  
(4)

\[ C(r, z, t) = \frac{M}{R_0^2 \varphi} F(z, t) \int_0^\infty J_1(\rho R_0) J_0(\rho r) \exp(-D_T\rho^2 t) d\rho \]  
(5)

\textbf{Chen et al. (2011)}

\[ \frac{\partial C(r = R, z, t)}{\partial r} = 0 \]  
(6)

\[ VC(r, z = 0, t) - D_L \frac{\partial C(r, z = 0, t)}{\partial z} = \begin{cases} \frac{M}{\varphi \pi R^2} \delta(t) & 0 \leq r \leq R \\ 0 & R \leq r \leq \infty \end{cases} \]  
(7)

\[ C(r, z \to \infty, t) = 0 \]  
(8)

\[ C(r, z, t) = \frac{\sigma}{\varphi^{\frac{1}{3}}D_L t} \sum_{n=0}^{\infty} \frac{1}{\lambda_n} \exp \left[ - \frac{(Vt - z)^2}{4D_L t} - D_T \lambda_n^2 t \right] 
- \frac{V}{2D_L} \exp \left( \frac{Vz}{D_L} - D_T \lambda_n^2 t \right) \text{erfc} \left( \frac{z + Vt}{\sqrt{4D_L t}} \right) \left( \frac{\rho^2}{R^2} + \frac{2\rho J_1(\lambda_n \rho) J_0(\lambda_n r)}{R^2 J_0(\lambda_n R)^2} \right) \]  
(9)

\[ D_L: \text{longitudinal dispersion coefficient} \quad [L] \]
\[ D_T: \text{transverse dispersion coefficient} \quad [L] \]
\[ \varphi: \text{soil porosity} \quad \text{[dimensionless]} \]
\[ V: \text{pore-water velocity} \quad \text{[LT}^{-1}] \]
\[ M: \text{mass of tracer} \quad \text{[M]} \]
\[ C(r, z, t) = \frac{M}{R_0 \pi \varphi} F(z, t) \int_0^\infty J_1(\rho R_0) J_0(\rho r) \exp(-D_T \rho^2 t) d\rho \quad (10) \]

\[ C(r, z, t) = \frac{M}{4\varphi D_T \sqrt{D_L \pi^3 t^3}} \exp\left[-\frac{(z-Vt)^2}{4D_L t} - \frac{r^2}{4D_T t}\right] - \frac{VM}{8\pi \varphi D_T D_L t} \exp\left(\frac{Vz}{D_L} - \frac{r^2}{4D_T t}\right) \text{erfc}\left(\frac{z+Vt}{2\sqrt{D_L t}}\right) \quad (11) \]

\[ C(r, z, t) = \frac{M}{4\varphi D_T \sqrt{D_L \pi^3 t^3}} \exp\left[-\frac{(z-Vt)^2}{4D_L t} - \frac{r^2}{4D_T t}\right] \quad (12) \]

\[ C(r, z, t) = \frac{\sigma}{\varphi \sqrt{D_L \pi t}} \sum_{n=0}^\infty \frac{1}{\lambda_n} \left\{ \exp\left[-\frac{(Vt-z)^2}{4D_L t} - D_T \lambda_n^2 t\right] \right. \\
\left. - \frac{V}{2D_L} \exp\left(\frac{Vz}{D_L} - D_T \lambda_n^2 t\right) \text{erfc}\left(\frac{z+Vt}{\sqrt{4D_L t}}\right) \right\} \left(\frac{\rho^2}{R^2} + \frac{2\rho J_1(\lambda_n \rho) J_0(\lambda_n r)}{R^2 \left| J_0(\lambda_n R)\right|^2}\right) \quad (13) \]
\[
V = 1.16 \text{ (cm/h)} \\
M = 300 \text{ g} \\
\phi = 0.44 \text{ (cm}^2/\text{h)} \\
D_T = 0.1 \text{ (cm}^2/\text{h)} \\
D_L = 1 \text{ (cm}^2/\text{h)} \\
R_0 = 5 \text{ (cm)}
\]

(r->\infty, z->\infty, (10) Zhang et al. (2006))

(r->R, z->\infty, (13) Chen et al. (2011))

(r->\infty, z->\infty, R_0->0, (12) Zhang et al. (2006))

(r->\infty, z->\infty, R_0->0, when z is far away (13))

Zhang et al. (2006)
Result
<table>
<thead>
<tr>
<th>depth</th>
<th>Outer Ring (r=60 cm)</th>
<th>Middle Ring (r=30 cm)</th>
<th>Inside Ring (r=2.5 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>z=7 cm</td>
<td>z=7 cm</td>
<td>z=7 cm</td>
<td></td>
</tr>
</tbody>
</table>

Constant Head High: _____10_____ (cm)

Observation point

B: r=5 cm, z=30 cm
C: r=5 cm, z=30 cm
D: r=10 cm, z=50 cm
E: r=10 cm, z=50 cm
<table>
<thead>
<tr>
<th>Position</th>
<th>Time(min)</th>
<th>Cl(ppm)</th>
</tr>
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<tbody>
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<td>0</td>
</tr>
<tr>
<td></td>
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<td>6.98</td>
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<tr>
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<td>32</td>
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<tr>
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<tr>
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<td>32</td>
<td>8.72</td>
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</tbody>
</table>
Summary
• Test time of D,E points is not enough.
• Tracer mass is not enough.
• More sampling times.

• Modify calibrated head tanks and suction cup.
• FDM
END