한국지하수토양환경학회 추계학술발표회
2004년 9월 9~10일 전 주 대 학 교

Experimental and Numerical Sensitivity Analyses on Push Pull Tracer Tests

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Abstract

Single-well tracer tests, especially push pull tracer tests, are more effective to estimate hydraulic parameters and microbial metabolic activities in terms of duration and cost compared to multi-well tracer tests. However, there are some drawbacks in accuracy, complicated data analysis and uniqueness. These shortages are thought to be derived from the applied conditions which affect mass recovery curve and breakthrough curve. Factors such as extraction rate, resting period, hydraulic conductivity and hydraulic gradient are considered as the major factors determining the mass recovery rate and shape of the breakthrough curve. The results of the sensitivity analysis are summarized as follows: 1) the significant change in concentration of breakthrough curve is obtained when the extraction rate increases. This effect would also be much higher if the hydraulic conductivity is lower; 2) the mass recovery rate decreases with the increase of resting time, and the difference of mass recovery rates for different resting times is inversely proportional to the hydraulic conductivity; 3) the sensitivity values decrease with time. The hydraulic conductivity affects not only the early period, but the later period of the breakthrough curves; 4) The influence of the hydraulic gradient on the breakthrough curves is greater at earlier stage than at later stage. The mass recovery rate is inversely proportional to the hydraulic gradient.

key words : push pull tracer tests, groundwater, tracer tests, moment method, analytical solution, numerical solution, laboratory experiments, sensitivity analysis, mass recovery rate, extraction rate, resting time, hydraulic conductivity, hydraulic gradient.

1. Introduction

Sensivity analysis was used to identify the important factor and serves information on the experimental design to obtain an appropriate parameter. Sensitivity is the partial derivative of tracer concentration with respect to a change in the value of a parameter (Knopman and Voss, 1987 and Harvey et al., 1996),

$$S_{ij} = \frac{\partial C_i}{\partial P_j} \quad (1)$$

where S_{ij} is the sensitivity of push pull tracer concentration at time i to the j th parameter, C_i is the concentration at time i, and P_j is the j th parameter. A large value (either positiveor negative) in the sensitivity parameter, at a particular time, is sensitive to a given parameter; a small number value would indicate that the model is insensitive to the parameter (Haggerty et al., 2001). The sensitivity analysis was performed with experimental data and numerical results. The analysis of sensitivities is the study of model behavior in response to perturbations in parameters (Knopman and Voss, 1987). Sensitivity analysis has been mainly applied to solutions of physical and chemical models (Harvey et al., 1996). We, however, applied the sensitivity analysis to the results of push pull experiments. The performance would also give an insight on the experimental design.

2. Method and Materials

The results of push pull experiments performed under the various conditions are used for the sensitivity analysis. As mentioned before, the applied parameters are extraction rate, resting time, hydraulic conductivity, and gradient. We used the concentrations at similar time interval to calculate the sensitivity.

2.1 Experimental and Numerical setting for Push Pull Tracer Tests

The Experimental setting consisted of three homogeneous coarse, medium, and fine sand layers (15cm thick). Clayey layers, 2 cm thick, were embedded within two sand layers to prevent the interaction between adjacent layers (Figure 1).

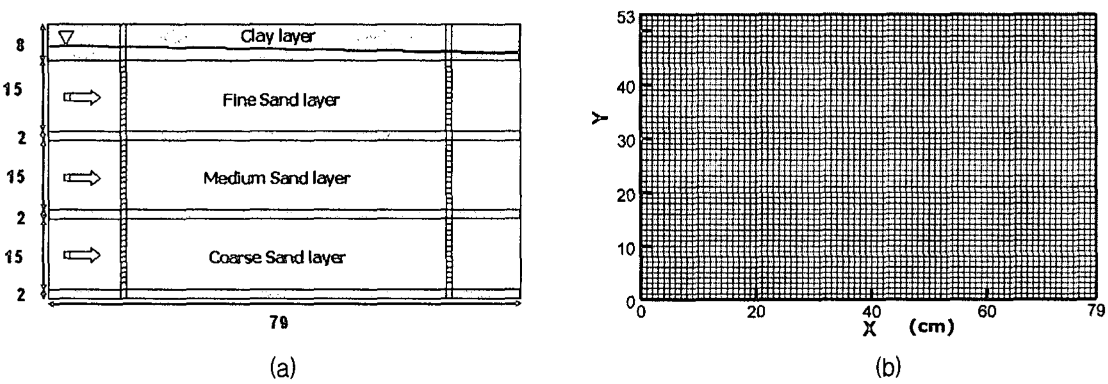

Figure 1 Experimental (a) and Numerical (b) settings

Push pull experiments were performed under the various conditions, which were extraction rates, resting times, and hydraulic gradients in coarse, medium, and fine sand layers. The hydraulic gradients were set to 6.33×10^{-3}, 1.27×10^{-2}, and 3.16×10^{-2} according to Altman et al (2002)

2.2 Sensitivity to Extraction Rate

the extraction rate gives significant effects on early part of breakthrough curve and the effects are higher when the hydraulic conductivity is lower. the concentration observed at a time decreases with the extraction rate. However, the mass recovery rate increases with the extraction rate in spite of decreasing breakthrough curve. Thus, the extraction rate gives more effect on the material of lower hydraulic conductivity than that of higher hydraulic conductivity. it can be said that both the experimental and numerical results are same in the point of view of affecting on early time of breakthrough curve.

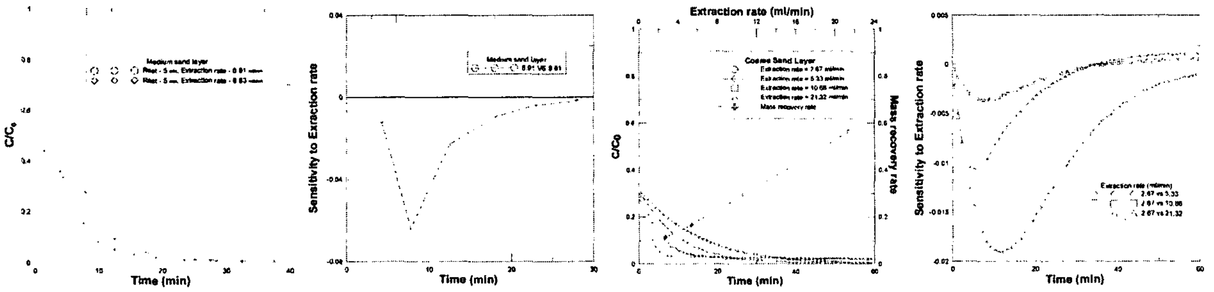

Figure 2. Breakthrough curves and sensitivity to extraction rate. (a) and (b); Experimental Breakthrough curve and sensitivity value, respectively. (c) and (d); Numerical breakthrough curve and sensitivity value, respectively.

2.3 Sensitivity to Resting Time

The notable feature in comparison to the influence of extraction rate is that the calculated sensitivity values with time are negative (see Figure 3 (b) and (c)). The negative sensitivity values are caused by the reason that the extraction rate is proportional to the mass recovery rate so the obtained concentration at a time increases with the extraction rate, however the resting time is vice versa. The mass recovery rate is inverse proportion to the resting time.

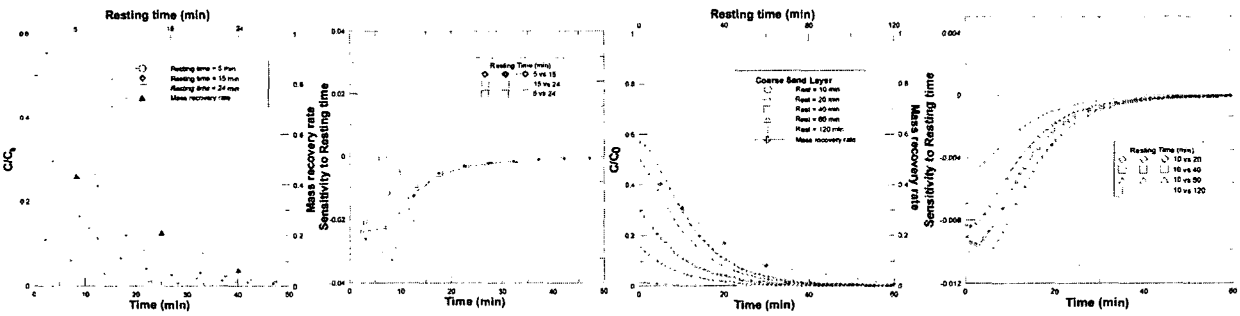

Figure 3. Breakthrough curves and sensitivity to resting time.

2.4 Sensitivity to Hydraulic Conductivity

The effect of hydraulic conductivity on the push pull test results is that the sensitivity values decrease with time. In comparison to the sensitivity to resting time, the sensitivity to hydraulic conductivity decreases more slowly with time. This behavior would be more significant when the difference between resting time is smaller up to a certain value.

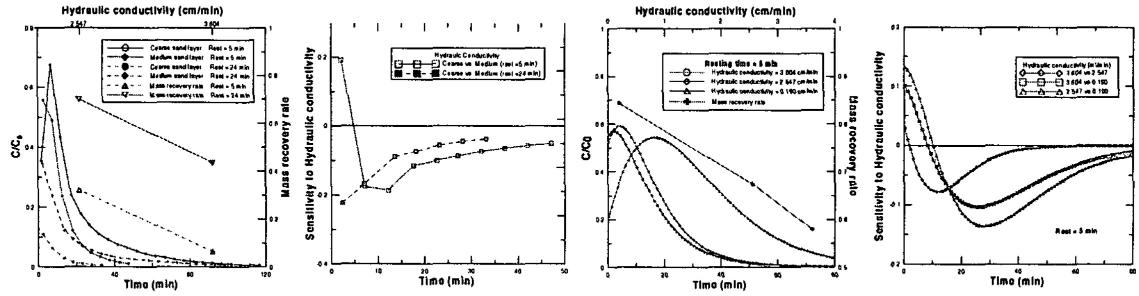

Figure 4. Breakthrough curves and sensitivity to hydraulic conductivity.

2.5 Sensitivity to Hydraulic Gradient

Figure 5 (a) is the breakthrough curves in fine sand layer. The early stage of breakthrough curves, from start to the peaks, are same each other. Thus the calculation of sensitivity values within this stage is near zero (see Figure 5 (b)). In this case, it can be inferred that the hydraulic gradient gives less influence on early stage than late-time.

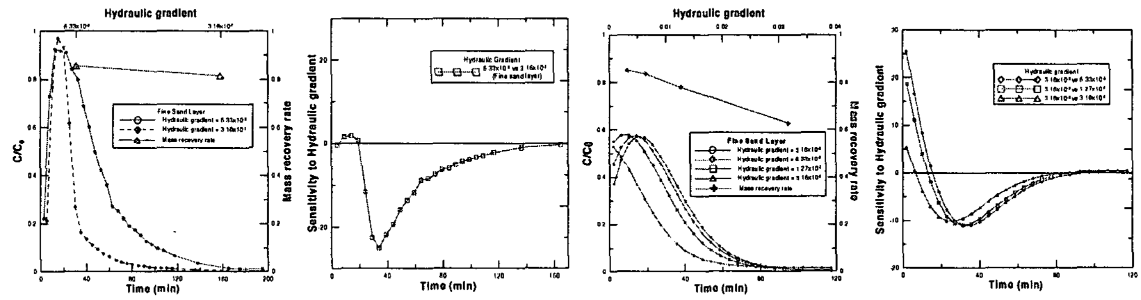

Figure 5. Breakthrough curves and sensitivity to hydraulic gradient.

3. Results and Discussion

For the sensitivity to extraction rate, the calculated sensitivity values are somewhat lower than those from coarse and medium sand layers. It is considered that the effect of resting time on the push pull tests is proportional to the hydraulic conductivity. For the sensitivity to resting time, longer resting time yields smaller mass recovery rate. The difference is larger at the early period of pumping than at late part of the campaign. For the sensitivity to hydraulic conductivity, it does also affect on an early part of breakthrough curve, however, the effects are relatively lower than other factors. Lastly, for the case of hydraulic gradient, the mass recovery rate is inversely proportion to the hydraulic gradient.

4. References

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Acknowledgement

This research was supported by a grant from Sustainable Water Resources Research Center of 21st Century Frontier Research Program and AEBRC at POSTECH.