한국지하수토양환경학회 춘계학술발표회
2004년 4월 16~17일 국립환경연구원

Effect of Degradation Processes on Optimal Remediation Design Sorption and First-Order Decay Rate

Dong-Kyu Park, Nak-Youl Ko, Kang-Kun Lee

School of Earth and Environmental Sciences, Seoul National University
e-mail: ecolede1@snu.ac.kr

<요 약 문>

Optimal remediation design using the pump and treat(P&T) method and natural attenuation was accomplished in consideration for degradation processes, such as sorption and first-order decay rate. Variation of both sorption and first-order decay rate has influence on design of optimal remediation application. When sorption effect increases, the more pumping rate and pumping wells are required. The location of operated wells is on the centerline of contaminant plume and wells near hot spot are mainly operated when sorption effect increases. The higher of first-order decay rate, the less pumping rate is required. These results show that the degradation processes have to be considered as one of the essential factors for optimal remediation design.

Key word : remediation design, optimization, genetic algorithm, sorption, first-order decay

1. Introduction

P&T may be the most conventional method for groundwater containment and cleanup problems. Natural attenuation is to remove contaminant throughout natural processes, for example, bioremediation caused by intrinsic microbe. Interest in this method have increased due to the complexity of subsurface system and the inherent problems of conventional method like pump & treat method. Thus, the combination of above two methods may be very useful for accomplishment of groundwater remediation. Recently, Genetic algorithm (GA) that is one of the global optimum search methods is often used to design the system of optimal remediation strategy (McKinney and Lin, 1994; Ritzel et al., 1994; Zheng and Wang, 2002).

The properties of the degradation processes, like sorption and first-order decay rate, are often sensitive factor and may have large influence on the optimal design. In this study, it is examined how the changes of sorption and first-order decay rate have an influence on the remediation design..

2. Methodology

There are two sets of variables in the P&T application. Decision variables are pumping rates, locations and the number of wells. State variables are the hydraulic head and drawdown, and the contaminant concentration. The simulation-optimization model used in this study explains next two procedures: (1) The simulation model updates the state variables using given decision variables. (2) The optimization model evaluates them and selects the optimal decision variables according to the inherent optimum search algorithm with constraints for decision variables and/or state variables. MODFLOW(Harbaugh and McDonald 1996), and MT3D(Zheng 1990) are used in the simulation model in order to evaluate groundwater flow and transport. In the optimization model, GA is used because of complex objective function and constraints (Goldberg 1989). GA has three basic operators: reproduction, crossover, and mutation. These operators make the optimum searching process represented in the optimization model as they work on gene in cell. It is readily coupled with other simulation model like MODFLOW and MT3D and so the domain with complicate boundary condition and initial condition for groundwater flow and contaminant transport can be applied easily (Askoy and Culver 2000; Zheng and Wang 2002).

3. Application for Theoretical Condition

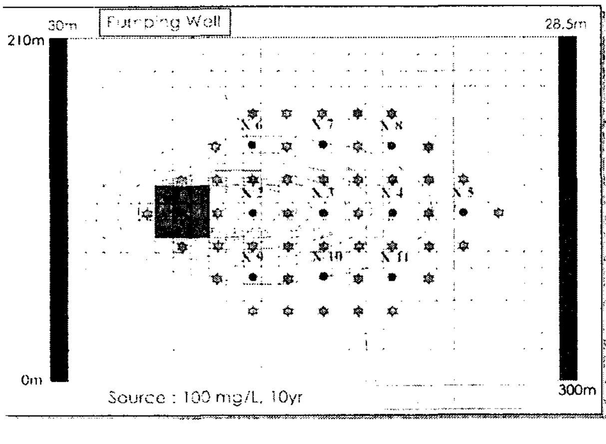

Figure 1. Contaminated domain for remediation

Parameter	Value
Hydraulic conductivity, K(m/sec)	5.0×10^{-5}
Effective porosity, n_e	0.25
Aquifer thickness, b(m)	30
Longitudinal dispersivity, α_L(m)	6.855
Transverse dispersivity, α_T(m)	1.371
Medium bulk density, ρ_b(kg/m^3)	1700
Specific yield, S_y	0.25

Table 1. parameters for aquifer and contaminant

3.1 Domain

For the numerical experiments, a homogeneous and isotropic aquifer system is generated. It is discretized into 30 by 21 finite-difference blocks (Figure 1). The leakage of contaminant for 10 years is assumed to make the initial condition for remediation. X1 is on hot-spot and the outmost contour of contamination is 1 mg/L, and others are multiple of 10 mg/L sequentially. Other information for aquifer and contaminant is in Table 1.

3.2 Experimental settings

To evaluate the effect of sorption and first-order decay rate, various values of them are applied

(Figure 2~5). Total remediation time were 3 years, former 2 years are set to periods P&T operated and latter 1year is set to periods nothing operated like applying natural attenuation.

3.3 Objective function

The objective function used in this study is given by:

$$Minimization \quad \sum_{j=1}^{m}\left\{ \sum_{i=1}^{n} Q_{i,j}(q_{i,j},\ t_{i,j})\right\} + N_{well} + \omega(C^{\max},\ C^{*},\ s^{\max},\ s^{*}) \times P \qquad (3)$$

where $Q_{i,j}$ is the pumping volume of the i-th well for the j-th period (m3); $q_{i,j}$ is the pumping rate of the i-th well of the j-th period (m3/day, $0 \le q_{i,j} \le 300$); $t_{i,j}$ is the pumping duration of the i-th for j-th period (day); N_{well} is the number of operated pumping wells; ω is the is the weighted factor for penalty value (dimensionless); $C^{\max}$ and $s^{\max}$ are the maximum values of concentration, and drawdown at the end of remediation process (mg/L, m); C* and s* are the constraint values of concentration and drawdown for the remediation system (mg/L, m, C* is 1.0 mg/L and s* is 10 m, respectively); P is the penalty value (dimensionless).

4. Results

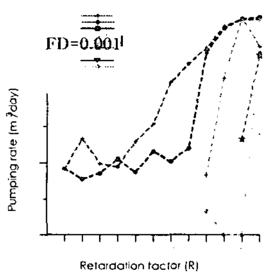

Figure 2. pumping rate with sorption at first-order decay rate=0.001(day-1)

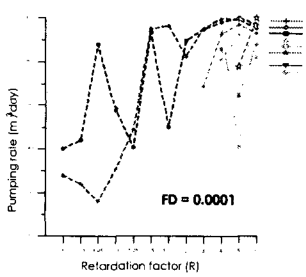

Figure 3. pumping rate with sorption at first-order decay rate=0.0001(day-1)

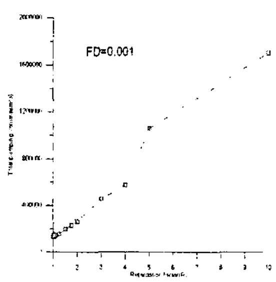

Figure 4. Total pumping volume with sorption at first-order decay rate = 0.001(day-1)

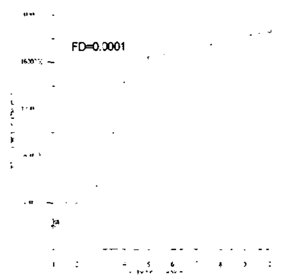

Figure 5. Total pumping volume with sorption at first-order decay rate = 0.001(day-1)

As the retardation factor(R) is increases, the pumping rates and number of operated pumping wells (Figure 2, 3) and the total pumping volume increase (Figure 4, 5). For all sorption cases of the higher first-order decay rate (FD=0.001), less pumping rate was required and the total pumping volume is lower than that of lower first-order decay rate condition. The locations of the wells mainly distributed on the centerline of contaminant plume. Especially X2 and X3 were mainly used, so it means that down-gradient wells near the contaminant source are mostly operated. As the sorption increases, the pumping wells close to the hot spot is operated with more pumping rate, and X2 has assigned the most pumping rate for many cases. Except for cases that R is 10, GA optimizes remediation design in all cases. Particularly for cases that R is larger than 3, more than three of wells were operated.

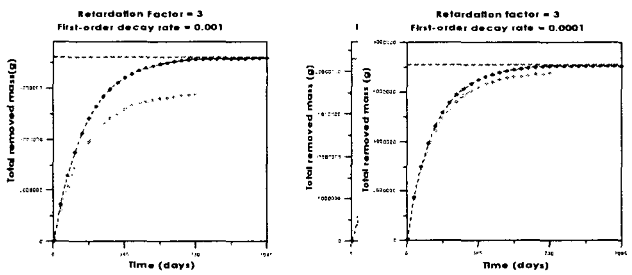

Figure 6. Total removed mass with time by pumping and biodegradation in each R and FD

For some cases of strong sorption, especially R=10, the concentration of contaminant did not reach at standard concentration of contaminant. Therefore, additional approaches suitable to strong sorption conditions will be needed for successive remediation.

Figure 6 shows that the efficiency of removing contaminant by pumping decreases after about 1.5 years. For an effective remediation design, the period when P&T is operated can be shortened if it satisfies remediation constraints. And if the natural attenuation mainly influenced by biodegradation can reinforce, the remediation cost may be reduced.

5. Summary and Conclusions

For successful remediation of contaminated groundwater, degradation processes of the site, such as soprtion and first-order decay rate, are the most important factors to be considered in remediation design stage. In this study, pump and treat method with natural attenuation were applied to remediation design of contaminated groundwater, and simulation-optimization model using genetic algorithm shows optimal pumping rate, number and location of using pumping well reflected the effects of sorption and first-order decay rate of the site. Changes of each sorption and first-order decay rate have influence on the design of optimal remediation. When retardation factor increases, the more pumping rate and pumping wells are required. Especially, the locations of operated wells are close to contaminant source, and down-gradient directions of groundwater flow on the centerline of contaminant plume. First-order decay rate has influence on pumping rate of remediation system, and as the first-order decay rate increases, the less pumping rate is required. These results show that the degradation processes have to be considered as one of the essential factors for optimal remediation design.

In the stronger sorption conditions, the remediation design may require additional pumping periods, higher pumping rates, and/or more number of pumping wells. Rather, other remediation techniques like monitored natural attenuation is required to increase the efficiency of remediation when P&T method is used.

Acknowledgement

This research was supported by a grant (code:3-5-1) from Sustainable Water Resources Research Center of 21st Century Frontier Research Program.

References

Askoy, A., Culver, T. B., 2000, Effect of sorption assumptions on aquifer remediation designs, Ground Water, 38(2), 200-208.

Chang., L. C., and C. T. Hsiao., Dynamic optimal ground water remediation including fixed and operation costs, Ground Water, 40(5), 481-490. 2002.

Goldberg, D.E., 1989, Genetic Algorithms in Search, Optimization and Machine Learning, Addison-Wesley publishing company, Inc., Massachusetts.

Harbaugh, A.W., McDonald, M.G., 1996, Users documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite-difference ground-water flow model, U.S. Geological Survey Open-File Report 96-485.

McKinney D. C. and M. -D. Lin, Genetic algorithms solution of groundwater management models, Water Resources Research, 30(6), 1897-1906, 1994.

Ritzel B. J., J. W. Eheart, and S. Ranjithan, Using genetic algorithms to solve a multiple objective groundwater pollution containment problem, Water Resources Research, 30(5), 1589-1603, 1994.

Yoon J.H. and Shoemaker C. A., Comparison of optimization methods for ground-water bioremidation, Journal of Water Resources Planning and Management, 125(1), 54-63, 1999.

Zheng, C., 1990, MT3D: A Modular Three-Dimensional Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions in Groundwater Systems, Report to the U.S. Environmental

Protection Agency, Ada, OK.
Zheng, C., Wang, P.P., 2002, A field demonstration of the simulation optimization approach for remediation system design, Ground Water, 40(3), 258-265.