Journal of Soil and Groundwater Environment Vol. 18(6), p. 32~37, http://dx.doi.org/10.7857/JSGE.2013.18.6.032

≪ Research Paper ≫

Development and Fabrication of Heating and Water Sparging Remediation System (HWSRS) for DNAPL-contaminated Groundwater Treatment

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ABSTRACT

The scope of this study was to develop, design, and build an ex-situ remediation system of using the heating and water sparging treatment for the highly volatile DNAPL (Dense Non-Aqueous Phase Liquid) contaminated groundwater, and to conduct pilot testing at the site contaminated with DNAPL. The TCE (Trichloroethylene) removal was at the highest rate of 94.6% with the water sparging at 70°C in the lab-scale test. The pilot-scale remediation system was developed, designed, and fabricated based on the results of the lab-scale test conducted. During the pilot-scale testing, DNAPL-contaminated groundwater was detained at heat exchanger for the certain period of time for pre-heating through the heat exchanger using the thermal energy supplied from the heater. The heating system supplies thermal energy to the preheated DNAPL-contaminated groundwater directly and its highly volatile TCE, CCl_4 (Carbontetrachloride), Chloroform are vaporized, and its vaporized and treated water is return edback to theheat exchanger. In the pilot testing the optimum condition of the HWSRS was when the water temperature at the 40°C and operated with water sparging concurrently, and its TCE removal rate was 90%. The efficiency of the optimized HWSRS has been confirmed through the long-term performance evaluation process.

Key words : DNAPL, Heating treatment, TCE, Volatilization

1. Introduction

DNAPL (Dense Non-Aqueous Phase Liquid) has lower solubility and higher density than water, because of these chemical and physical properties, DNAPL leaked into the subsurface and is continuously migrating downward through subsurface even after reached aquifer, and forms residual DNAPL (Lee, 2013). Of the DNAPLs, TCE (Trichloroethylene), typical chloride organic compounds in Korea, is frequently detected in the groundwater and known as a cause of groundwater contamination due to the metal washing and polishing with solvents in industrial complex (Lopes and Bender, 1998; Yang et al., 2012). It takes long time to remediate groundwaters and soils contaminated with TCE and other chloride organic compounds because residual DNAPL retained in the unsaturated zone for a long period of time (Kim, 2004; Luciano et al., 2010). It has been confirmed that groundwater near the Woosan Industrial Complex in Wonjoo-si, Kangwon-do is contaminated with TCE (Yang et al., 2012). And the result of environmental study performed for the surrounding areas of the Woosan Industrial Complex over the several years, the site was determined to be contaminated with TCE and other DNAPL. Generally, it is difficult to remove contaminants with the short carbocyclic aliphatic chains by traditional treatment technologies such as coagulation, precipitation, and filtration methods (Wood and DeMarco, 1980).

Generally, there are some limitations to bioremediation in areas contaminated with the high concentrations of chlorinated organic compounds. Its characteristics may be changed to other toxic substances, and it takes longer to remediate (Den et al., 2006). The chemical treatment has somewhat advantage that chloride organic compounds can be treated faster, not affected by physical/chemical properties and concentration levels of contaminants like TCE, however, it has own limitations: economic burden of chemicals (Amarante, 2000).

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Received : 2013. 9. 23 Reviewed : 2013. 11. 26 Accepted : 2013. 11. 26
Discussion until : 2014. 1. 31

Air sparging is one of the technologies to remediate groundwater with dissolved volatile contaminants in the aquifer by transporting contaminants to the ground due to three mechanisms, which are advection, dispersion, and/or diffusion, and its removal efficiency of contaminants has been pilot-tested at several field sites. (Marley et al., 1992; Johnson et al., 1993; Lundegard and Labrecque, 1995; Reddy et al., 1995; Reddy and Adams, 1998; Rabiduar et al., 1999; Johnston et al., 2002); however, there has been no studies performed for the removal of chlorinated organic compounds using direct heating and reported to date. Heated DNAPL contaminants are removed through volatilization of the chlorinated organic compounds with high volatility such as TCE, CCl_4, and Chloroform, and etc.

This study was to develop an ex-situ remediation technology; as the water is heated and re-circulated through the water sparging systems, the vapor pressures and their high Henryís law constants of the chlorinated volatile organic compounds (CVOC) constituents increase. With the temperature increase, highly volatile CVOCs will vaporize quickly, enabling their removal by vapor extraction.

2. Materials and Methods

2.1. The Lab-scale Optimization Study of HWSRS

The lab-scale experiment was conducted to develop design and build a heat treatment system. It was intended to verify this heat treatment system is feasible to treat contaminants; furthermore, to verify the treatment efficiency affected by the water temperature variations. 300 mL of DNAPL-contaminated groundwater sample in a 500-mL amber glass container is heated using the water bath method to control the sample temperatures to 30ºC, 50ºC, and 70ºC respectively, and then raises water temperatures to the target temperatures (Fig. 1). This same system was tested with the sparged-waters to learn its efficiency of the water-sparging effects.

2.2. Optimization Study of Pilot-scale HWSRS

A pilot-scale system was designed and fabricated based on the results of lab-scale test conducted. A water-to-water heat exchange takes place in heat-transfer water that circulates through the pump, absorbs heat, and then flows through a heat exchanger to transfer its heat to DNAPL-contaminated groundwater in a heat-exchanger tank. DNAPL-contaminated groundwater is retained in the heat exchanger tank for a period of time for the water heating.

Fig. 1. Lab-scale experimental of heating treatment for DNAPL groundwater.

In the heating tank capable of processing 1-ton per cycle of contaminated water, additional thermal energy is added to the preheated DNAPL-contaminated water through the electric heater. Its thermal energy vaporizes the highly volatile TCE, CCl_4, and Chloroform, at the same time the water-sparge nozzlesa reactivated by the pumped water from the heat exchanger. The volatilized gas-phase DNAPL transfer pump coupled with off-gas treatment systems such as activated carbon adsorption tower were developed. The water, with the gaseous pollutants removed, returns to the heat exchanger retention tank. To optimize the HWSRS, three sequential tests were conducted in the following order: 1) variation characteristics of the DNAPL treatment efficiency with heat treatment only, 2) operating water sparging system only, and 3) combined heating/water sparging with heater and spray nozzles operating simultaneously. The results from the test are summarized in Table 1.

2.2.1. Long-term performance evaluation HWSRS

A pilot-scale HWSRS was installed to demonstrate the applicability of the technology at the actual DNAPL contaminated site, and operated with 40ºC water temperature and 10- minutes water sparging (average 4 cycles per day),

Table 1. The optimal condition of pilot-scale HWSRS

Heating only	Water sparging only	Heating + water sparging
20°C	0 min	20°C + 30 min
30°C	10 min	30°C + 30 min
40°C	20 min	40°C + 30 min
50°C	30 min	50°C + 30 min
60°C	40 min	60°C + 30 min
70°C	50 min	70°C + 30 min
80°C	60 min	80°C + 30 min

For its long-term evaluation the system was operated 8-hour per day over 70 days.

2.3. HWSRS Analysis

The samples from the HWSRS optimization experiment and long-term performance evaluation studies were analyzed with the Varian's GC / MS, Purge & Trap, Column Model, CP-Select 624 CB (30 m 0.25 mm 1.4 μm), Column flow rate is set to 1.0 ml/min. Heating conditions are to hold for 2 minutes at 45°C, heat 6.0 (°C/min) from 45°C to 140°C and heat 20.0 (°C/min) from 140°C to 200°C, and injection temperature is set to 220°C with the split ratio of 20.

3. Results and Discussion

3.1. Optimization of HWSRS

300 mL of the DNAPL contaminated groundwater samples in 500 mL amber container was heated in the boiling water to control the inside sample temperature to 30, 50, 70°C each by maintaining each target temperature for 30 minutes (Fig. 1). With these same water temperatures, lab-scale tests were conducted with additional heating and water sparging applied. The effect of temperature on the TCE removal efficiency is shown in Fig 3(a). The removal rates increase with the higher temperatures, however, the efficiency of TCE removal was not significant. The further analysis of cost/benefit and treatment efficiency studies is needed for the temperature optimization of the pilot-scale tests. Test result performed for the additional water sparging process, simulating pressurized degassing after heat treatment is shown in Fig 3. As shown in the graph, when the temperature is high, removal efficiency of the heat treatment is high as well, and when the water sparging process is added, treatment efficiency is found to be increased significantly. Both of heat treatment and pressurized degassing processes use of its highly volatile DNAPL characteristics to its maximum extent, removal efficiency is increased with temperature rises. The pilot-scale HWSRS was installed and tested based on the results of lab-scale studies at the DNAPL- contaminated site to determine the optimal operating conditions. However, unlike the lab-scale tests, the removal efficiency was not increased significantly over 40°C and higher temperature ranges, the best removal efficiency was shown within 10 minutes with water sparging applied. (Fig. 4.). The other reason why the pilot-scale optimization of conditions are different from those of lab-scale test is that bigger the system provides a temperature rising time faster,

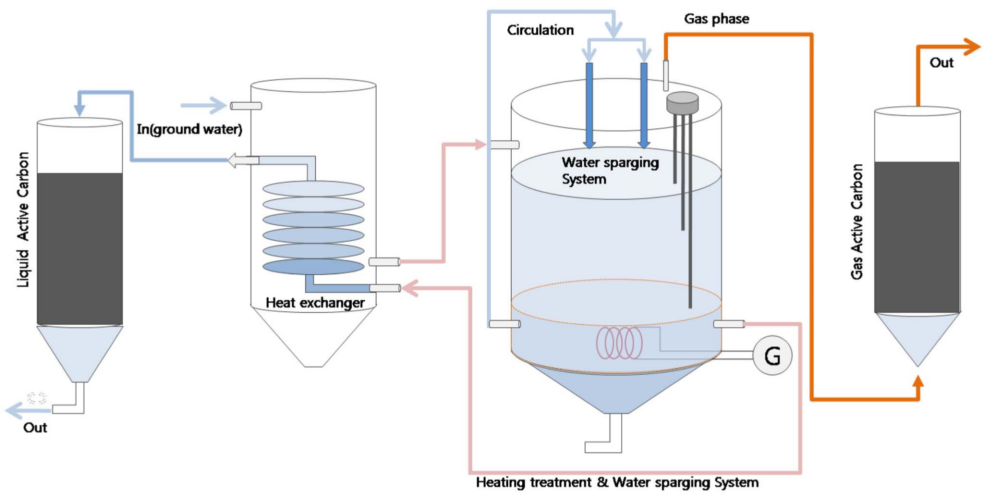
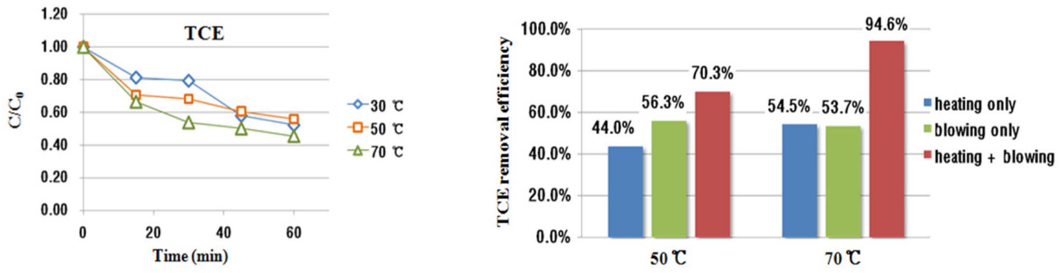


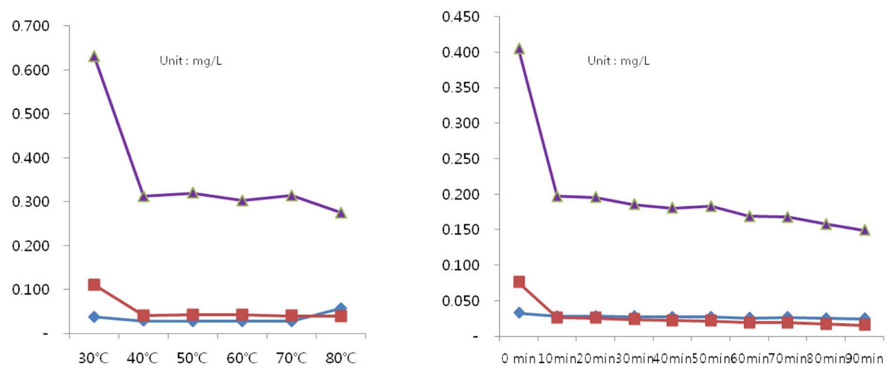
Fig. 2. Diagram of Heating & Water Sparging Remediation System for design & manufacture.



(a) (b)

Fig. 3. Lab-scale experiment of TCE results (a) Heating only 30°C, 50°C, 70°C (X: minute, Y: permittivity) (b) ■ heating only, ■ water sparging only, ■ heating & water sparging of heating treatment for DNAPL groundwater.

(a) Heating & Water Sparging Remediation System



(b) Heating only (c) Water sparging only

Fig. 4. Pilot-scale manufacture and experiment results (a) manufacture of Heating & Water Sparging Remediation System, (b) results of heating only, (c) results of water sparging only for DNAPL groundwater (▲ TCE, ■ CCl_4, ◆ Chloroform).

because of the slow groundwater convection the evaporation effect was reduced.

3.2. Long-term Performance Evaluation of HWSRS

The test was conducted that the system operating condition was set at the optimized temperature of 40°C, 10-minutes water sparging, and 1-ton per cycle of groundwater inflow rates for the long-term performance evaluation. The contaminant concentration levels of inflow and heating treatment system, and concentration levels and temperature of the treated water discharged through activated carbon filters were monitored.

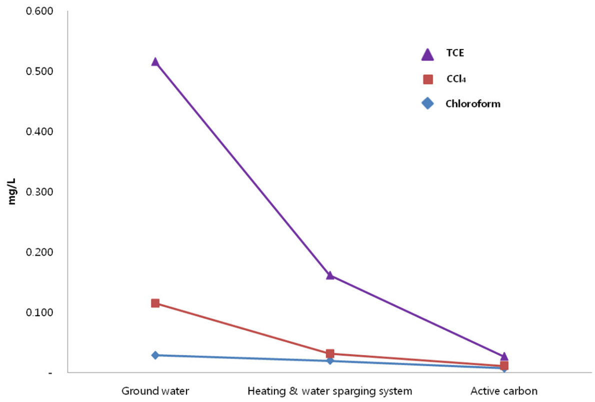


Fig. 5. Pilot-scale experiment results of HWSRS for DNAPL groundwater (▲ TCE, ■ CCl_4, ◆ Chloroform).

When a temperature was set to 40°C at the heating tank, the discharge temperature in the heat exchanger tank was approximately 30°C, which is 10°C lower due to the heat transfer to the inflow. The highest TCE concentration of inflow was 0.407 ppm, the lowest concentrations was 0.390 ppm, the mean concentration was 0.358 ppm, the highest CCl_4 concentration was 0.086 ppm, the lowest concentration was 0.031 ppm, the mean concentration was 0.063 ppm, the highest concentration of Chloroform was 0.028 ppm, the minimum concentration was 0.023 ppm, the mean concentration was 0.025 ppm. Judging from the long-term operation data of the TCE removal efficiency, the removal rate of heating treatment system was over 60% and the removal rate of discharge water from activated carbon adsorption was over 90%. The CCl_4 and Chloroform concentration levels of the inflow are too low to calculate the removal efficiency (Fig. 5.) Groundwater temperature remains (Yang., 2009). In addition, the effect on energy consumption can be reduced by circulating the warm discharge water through the piping and used for heating purpose. It is estimated that its electricity consumption can be reduced to the same as those of the summer months.

4. Conclusions

The study was to develop and design a pump and treatment system, Heating and Water Sparging Remediation System, which is one of ex-situ remedial technologies for the removal of TCE distributed/diffused DNAPL in groundwater. The method of enhanced volatilization of contaminants using direct heating and water sparging system was developed. HWSRS with 10 min reaction time at 40°C water temperature in the state of DNAPL distributed/diffused, showed approximately 90% of TCE removal efficiency and the somewhat environmentally friendly technology was developed because there is no by-product resulting from the remediation process since there was no chemicals used for this ex-situ remediation method. It is recommended to conduct further testing of the system at the site with high concentrations of DNAPL-contaminated groundwater.

Acknowledgements

This study is supported by Korea Environmental Industry & Technology Institute of Environment GAIA Project (173-092-012).

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