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# LONG TERM FIELD TEST ON AIR SPARGING PERFORMANCE

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## SYNOPSIS

Air sparging was applied to a site contaminated with tetrachloroethylene, toluene and other volatile substances. In this study site, a long term field test was conducted to examine the effects of removal mechanisms as well as the spread of contaminants from the test site. The results obtained in this study were the following; in many monitoring wells, the contaminant concentrations in groundwater smoothly decreased and were below detection limit after about 150 days. The groundwater disturbance arising from air injection induced the mixture and dilution of groundwater within and outside the region of injected air flow and consequently resulted in enlarging the zone of influence of injected air. The decrease in toluene concentration in groundwater was faster than tetrachloroethylene, because toluene was easily degraded by increasing dissolved oxygen concentration in groundwater due to air injection. Finally, this operation for air injection did not induce the spread of contaminants from the test site.

## INTRODUCTION

Air sparging coupled with soil vapor extraction has been developed and applied to remove volatile contaminants from subsurface environment instead of groundwater extraction coupled with soil vapor extraction (1). The groundwater extraction requires water treatment like aeration on the ground. On the other hand, air sparging facilitates contaminant volatilization with air injected into groundwater and removes contaminant gas by soil vapor extraction in the unsaturated zone. The advantages offered by this technology are that water disposal is eliminated, the same facilities of soil vapor extraction are used and the restoration period is shortened. Additionally, this technology accelerates aerobic biodegradation of contaminants like petroleum hydrocarbons by increasing dissolved oxygen concentrations in groundwater (2,3).

Because injected air movement in groundwater is very important in applying air sparging effectively, most efforts for this technology with the field tests (4,5), the laboratory experiments (6-8) and the numerical simulations (9,10) focused on determining the injected air flow pattern and designing the optimal placement and operation conditions of the air injection wells. The authors also investigated the details of the injected air movement in groundwater by a previous short term field test (11). This paper presents the results of the long term field test conducted to estimate the removal mechanisms for contaminants in groundwater as well as the spread of contaminants from the test site.

## FIELD TEST DESCRIPTION

The long term field test on air sparging performance was applied to the site contaminated with volatile substances like tetrachloroethylene, toluene etc. These substances have been utilized to produce industrial chemicals for many years. Fig.1 illustrates the vertical geological feature and contaminant contents in soil and groundwater. Perched water of 1.5 m thickness existed on clay layer and shallow groundwater between G.L.-11.5 m and G.L.-17.5 m in sand layer. Shallow groundwater flowed towards the southwest with an average velocity of 30 m $year^{-1}$. The

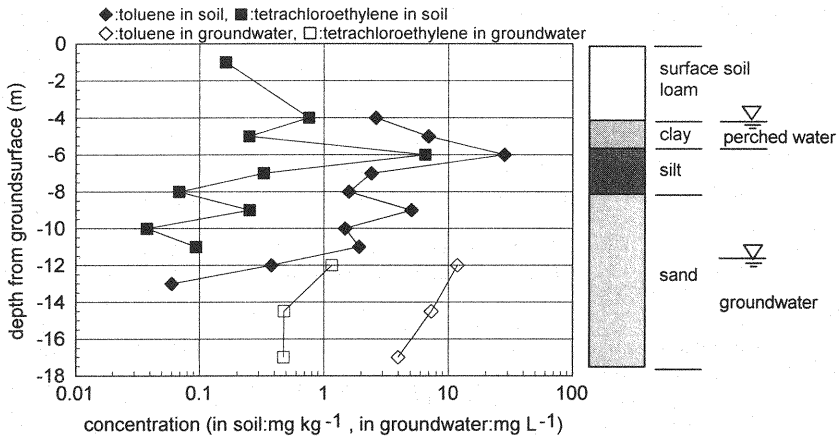


Fig.1 Vertical geological feature and contaminant contents in soil and groundwater

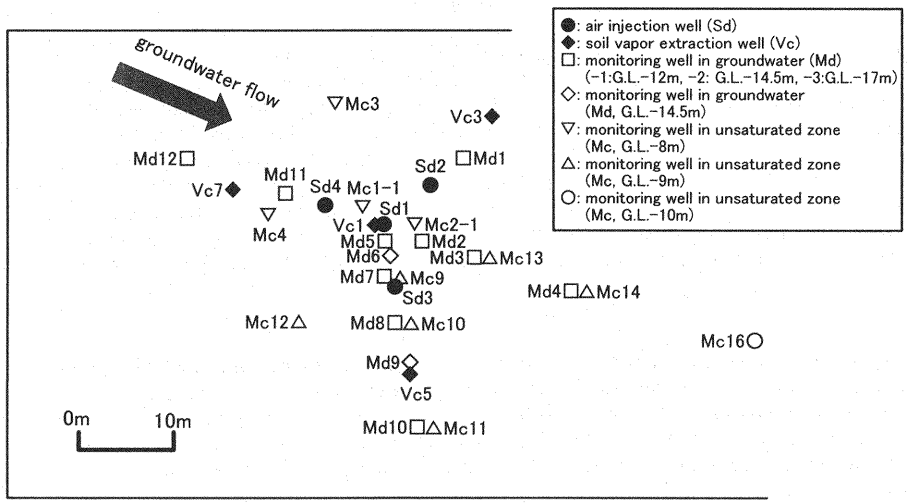


Fig.2 Horizontal placement of air injection, soil vapor extraction and monitoring wells

sand layer was very uniform and the permeability test confirmed that the sand layer was nearly horizontally isotropic. Plenty of tetrachloroethylene and toluene were present below ground and the contaminants in the clay and silt layers were much more than those in the sand layer. However, because it was difficult to send injected air to low permeable layers like clay and silt, air sparging was applied in shallow groundwater in this field test.

Fig.2 illustrates the horizontal placement of air injection, soil vapor extraction and monitoring wells. Air injection Sd1 and soil vapor extraction Vc1 wells were constructed at the center of this site. Three air injection wells of Sd2,Sd3 and Sd4 were constructed at a distance of 6 m from the center. Three soil vapor extraction wells, Vc3, Vc5 and Vc7, were positioned to surround the air injection wells in order to prevent contaminant gas which may reach the unsaturated zone from spreading outside the test site and the distance from the center was 15 m each.

All air injection wells were screened for the interval of 16.7 m and 17.2 m and all soil vapor extraction wells for the interval of 8 m and 11 m below ground. The groundwater monitoring wells were basically 12 m, 14.5 m and 17 m below ground, and a screen of 0.5 m thickness was installed at the bottom of the each well. The monitoring wells in the unsaturated zone were basically 9 m, however some wells were 8 m or 10 m below ground. The screen

Table 1 Operation condition

| | |
|---|---|
| Air injection time | 7 months (pulsed operation, one air injection well has been operated for one hour by turns.) |
| Air injection well | Sd2, Sd3, Sd4 |
| Air injection rate | 120 L $min^{-1}$ |
| Soil vapor extraction time | continual operation during the field test |
| Soil vapor extraction well | Vc1, Vc3, Vc5, Vc7 |
| Soil vapor extraction rate | 120 L $min^{-1}$ |
| Soil vapor treatment | activated carbon adsorption |

of 0.2 m thickness was installed at the bottom of the each well.

Table 1 shows the operation condition for this field test. Air was intermittently injected through the Sd2, Sd3 and Sd4 wells. One air injection well was operated for one hour by turns, and the rate was 120 L $min^{-1}$ each. Air injection was on occasions turned off for one week to pump up soil gas and groundwater. Soil vapor was continuously extracted, and four wells of Vc1, Vc3, Vc5 and Vc7 were operated at the rate of 120 L $min^{-1}$ each.

## RESULTS AND DISCUSSION

### *Change in Contaminant Concentration in Groundwater*

Fig.3 illustrates the changes in contaminant concentrations in groundwater in Md2, Md7 and Md8 wells. Air injection started at 0 day in this figure. The decreases in contaminant concentrations between -83 to -74 days depended on the previous short term operations (11). In many monitoring wells, the contaminant concentrations

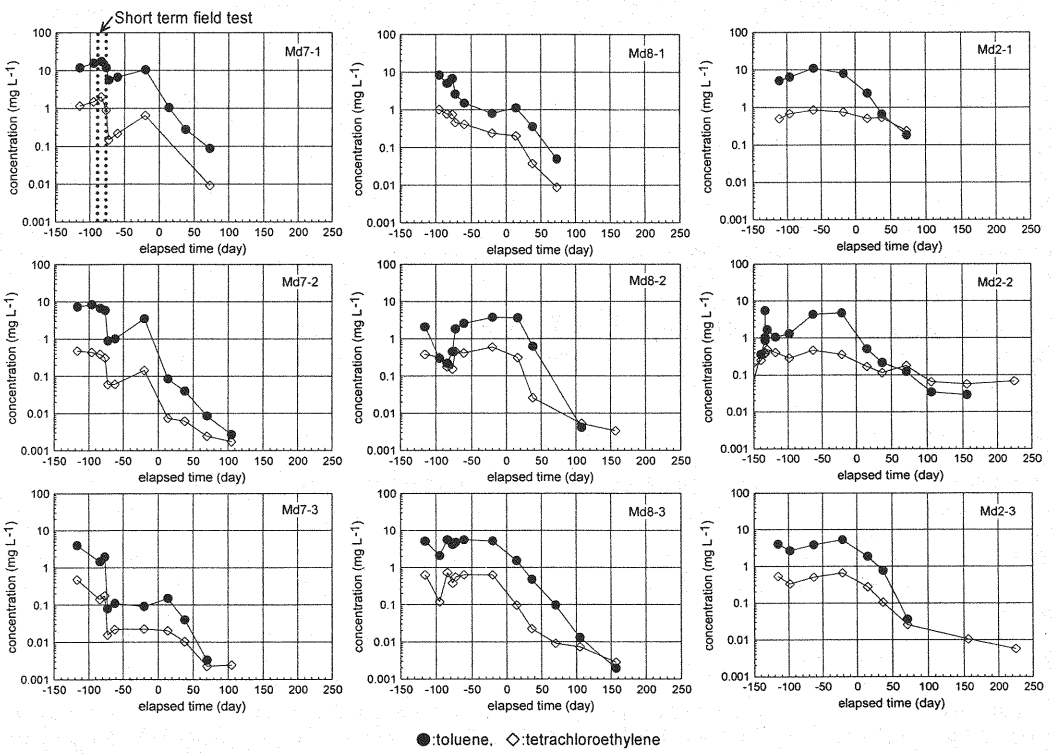


Fig.3 Changes in contaminant concentrations in monitoring wells

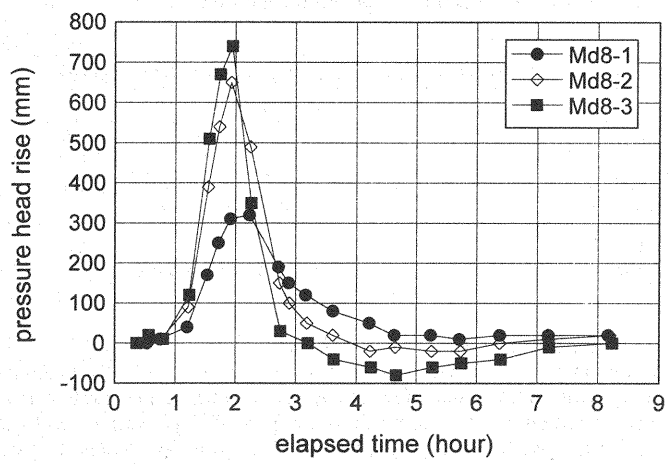


Fig.4 Changes in groundwater pressure heads in Md8 wells

smoothly decreased as soon as air injection started and were below detection limits (tetrachloroethylene:0.002 mg $L^{-1}$, toluene:0.003 mg $L^{-1}$) after about 150 days. However, there were no data in G.L.-12 m after 70 days, because groundwater table seasonally decreased and it was impossible to pump up groundwater. In Md8-2, -3 and Md2 wells which injected air did not sufficiently flow, the contaminant concentrations did not decrease in the short term operations (11), however decreased in this long term operation. And also, the decrease in toluene concentration was faster than tetrachloroethylene in many monitoring wells.

*Groundwater Disturbance*

Fig.4 illustrates the changes in groundwater pressures in Md8 wells during the short term operation. The initial pressure heads were almost the same in the monitoring wells before the operation. Therefore, the pressure head difference between the two wells during the operation was the hydraulic gradient and exhibited groundwater movement induced by air injection. Groundwater moved upward during air injection and downward after air injection turned off. This groundwater movement showed that groundwater was disturbed by air injection. The same phenomenon was recognized in some wells (11). This long term operation was the pulsed operation which one air injection well had been operated for one hour by turns, and therefore the same groundwater movement caused during the operation. As a result, groundwater outside the region of injected air flow, e.g. in Md8-2, -3 and Md2 wells in Fig.3, was mixed and diluted with groundwater of low concentration which decreased due to air injection, and the contaminant concentration also decreased. In other words, the groundwater disturbance resulted in enlarging the zone of influence which the contaminant concentration in groundwater decreased by air injection. The zone of influence was about 5.5 m in this operation.

*Aerobic Biodegradation of Toluene*

Fig.5 illustrates the changes in dissolved oxygen concentrations (DO) in Md2, Md7 and Md8 wells. There were no data in G.L.-12 m, because DO was not correctly measured. DO in Md7 and Md8 wells almost kept high during the operation. While DO increased after 30 days, however decreased to 1.5 mg $L^{-1}$ after that in Md2-2 well. On the other hand, DO gradually increased during air injection in Md2-3 well. DO in Md2 wells were lower than in Md7 and Md8 wells, so that the injected air did not sufficiently flow and groundwater was not disturbed enough near Md2 wells. Therefore, the decreases in contaminant concentrations were later than in Md7 and Md8 wells.

The increase in DO by air injection causes aerobic biodegradation of contaminants in groundwater. Toluene is easily degraded in an aerobic subsurface condition. Considering the increase in DO during the operation, not only volatilization into injected air but also aerobic biodegradation contributed to the removal of toluene from groundwater. On the other hand, as tetrachloroethylene is slightly degraded in an aerobic condition, volatilization into injected air is the only effective removal mechanism. The Henry's constant of tetrachloroethylene is larger than toluene and hence tetrachloroethylene is a more volatile substance. However the decrease in toluene concentration was faster than tetrachloroethylene in many monitoring wells. This fact showed the aerobic biodegradation of toluene contributed to the decrease in the concentration in this site.

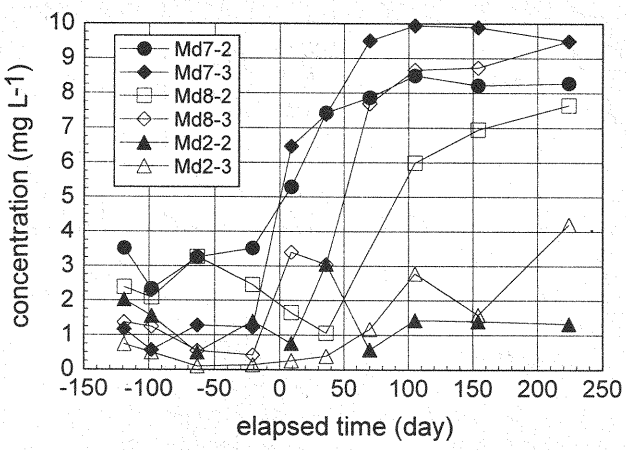


Fig.5 Changes in dissolved oxygen concentrations in monitoring wells

*Spread of Contaminant*

Fig.6 illustrates the horizontal distributions of tetrachloroethylene concentration in groundwater. The concentrations in the monitoring wells of Md1, Md2, Md7, Md8 and Md11 within a lateral distance 5.5 m apart from the nearest air injection wells decreased during the operation. These wells were placed within the zone of influence. On the other hand, because the monitoring wells of Md3, Md4 and Md10 were over laterally 10 m apart from the nearest air injection wells and placed outside the zone of influence, the concentrations did not decrease during the operation.

Because the Md3 and Md4 wells are located downstream of the air injection wells, the concentration in these wells were gradually influenced by the upstream concentration. The average groundwater velocity was 30 m $year^{-1}$ and the influence of Md2 well appeared in the concentration in the Md3 well within 60 days. The concentration in Md2-2 well decreased from 0.36 mg $L^{-1}$ before 21 days to 0.07 mg $L^{-1}$ after 106 days during the operation. However, the concentration in Md3-2 well maintained at about 0.5 mg $L^{-1}$ after 106 days. This was because the groundwater table had decreased from G.L.-11.5 m to G.L.-11.85 m for about 100 days from the air injection starting, so that the infiltration of above groundwater of high concentration(0.76 mg $L^{-1}$ in Md3-1 well after 71 days) kept the concentration in the Md3-2 well high. During the few months while the groundwater table was in a steady state, the concentration decreased after 224 days being affected from the upstream. The same phenomena were also recognized in the Md3-3, Md4 wells and for toluene. The concentration of about 0.5 mg $L^{-1}$ in the Md4-2 well after 224 days was influenced by upstream Md3-2 well whose concentration was 0.5 mg $L^{-1}$. The concentration in the Md10-2 well after 71 and 106 days increased due to the influence of above groundwater with high concentration. In conclusion it was determined that an increase in contaminant concentrations outside the zone of influence did not show the spread of contaminant from the test site.

## CONCLUSION

The long term field test on air sparging performance was applied to the site contaminated with tetrachloroethylene, toluene and other volatile substances. The results obtained in this study are as follows:

1) The contaminant concentrations in groundwater smoothly decreased and were below detection limit after about 150 days within the zone of influence.

2) Groundwater outside the region of injected air flow was mixed and diluted with groundwater of low concentration which decreased due to air injection, and consequently the contaminant concentrations also decreased during this operation. As a result, the groundwater disturbance arising from air injection resulted in enlarging the zone of influence.

3) Toluene concentration in groundwater decreased due to volatilization into injected air and aerobic biodegradation. And the decrease was faster than tetrachloroethylene which was more volatile substance but not aerobically degraded.

4) The contaminant concentrations in groundwater outside the zone of influence increased during the operation. However, it was induced by the infiltration of above groundwater with high concentration when the groundwater

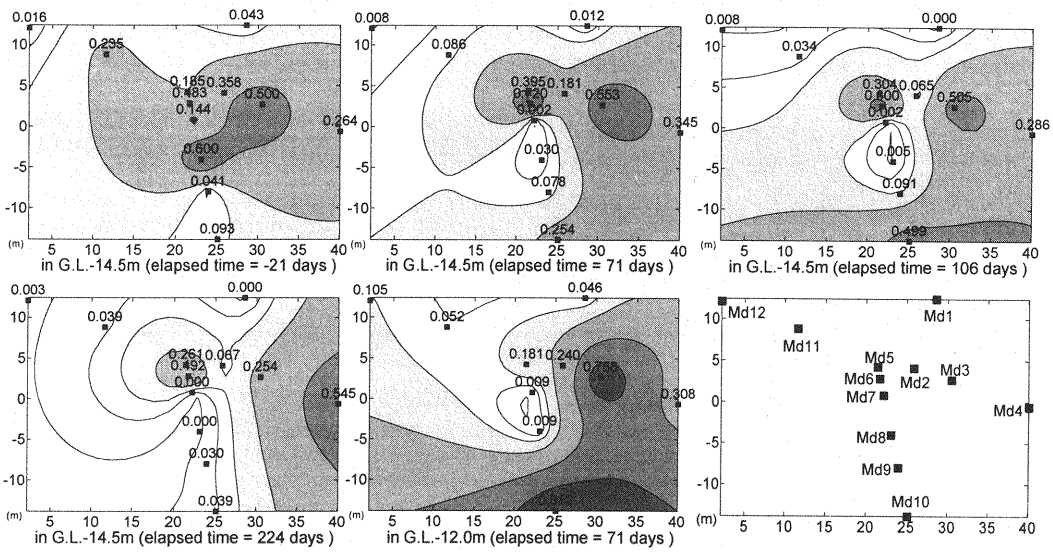


Fig.6 Horizontal distributions of tetrachloroethylene concentration

table decreased. In conclusion the increase in concentration outside the zone of influence was not affected by the spread of contaminant from the test site of the air injection.

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