Characterization of a PCE contaminated site by a partitioning interwell tracer test

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Abstract Partitioning tracers can be used to characterize non-aqueous phase liquids (NAPLs) like chlorinated solvents, within the subsurface. Partitioning tracer tests have been applied in the oil and gas exploration industry to characterize reservoirs for many years, but only recently in the field of remediation. In this study a large scale partitioning tracer test for the detection of PCE is conducted using bromide as a non-partitioning tracer and 2,4-dimethyl-3-pentanol, isopropanol and 1-hexanol as partitioning tracers.

INTRODUCTION

During the past ten to fifteen years many sites have proved to be contaminated with dense non-aqueous phase liquids (DNAPLs) such as chlorinated solvents (e.g. perchloroethylene). The cleanup of these sites is complicated due to the nature of DNAPL-contamination: DNAPLs accumulate in pools on top of less permeable layers. Contaminants slowly dissolve into the groundwater from these pools, causing large scale and long term groundwater pollution. Removal or containment of the "hot spot" is essential for a "finite" remediation of these sites. A cost-effective remediation requires characterization of the hot spot. Characterization of DNAPL pools and residual contamination, using conventional point measurements (drillings) was found to require too many measurements to be cost-effective.

Partitioning tracers can be used to identify NAPLs within the subsurface: a partitioning tracer test provides "evidence" of the presence of NAPLs. Furthermore, the amount and distribution of NAPLs in the subsurface can be estimated (Jin et al., 1995; Studer, 1997; Rao et al., 1998; Annable et al., 1997).

Partitioning Interwell Tracer Tests (PITT) have been applied in the oil and gas exploration industry to characterize reservoirs for many years, but only recently for remediation. The application of PITT for remediation has mostly been at the laboratory scale. A limited number of field tests have been carried out so far, mostly in America (Nelson & Brusseau, 1996). Until now partitioning tracers have not been applied at the field scale in The Netherlands. In this study a large-scale two dimensional partitioning tracer test for the detection of PCE was conducted. The injection experiment started in October and lasted until December 1999.
CONCEPT

Partitioning tracer tests are based on the difference in partitioning behaviour of tracers into NAPLs; partitioning tracers like 2,4-dimethyl-3-pentanol, isopropanol and 1-hexanol will partition into the NAPL (Jin et al., 1995) which causes retardation of the tracer compared to the groundwater flow characterized by a conservative tracer. Monitoring travel times and fate provides information on the retardation of the non-conservative tracers. The breakthrough curves of the tracers as a function of space and time are used as input for an inverse transport model, which is based on a technique described by Valstar (1997) to determine the spatial distribution of the retardation of the tracers in the subsurface. Column experiments are conducted to determine the relation between NAPL-saturation and retardation factors for the three non-conservative tracers. Combining these relations with the spatial distribution of the retardation of the tracers will provide a spatial distribution of the NAPL-saturation in the subsurface at the site.

TEST SITE DESCRIPTION AND TEST SETUP

Site description

For implementation of the pilot test, a suitable site was found at a former textile dying company in the province of Noord-Brabant in the Netherlands. Perchloroethylene (PCE) was used during the dying and cleaning process. Inadequate handling and storage of PCE and subsequent spillage caused the shallow subsurface below the buildings to be contaminated with PCE in the form of DNAPL.

The subsurface of the site comprises a 20 m deep sequence of alternating fine sand and loam layers and lenses known as the Nuenen group. The thickness of the loam layers and lenses ranges from just a few decimetres up to 1 m. Despite the small-scale nature of the loam layers (dimensions typically less than $20 \times 20$ m$^2$), the complex of loam layers acted as a barrier or geological trap for the downward movement of the DNAPL. In fact the initial site characterization showed that most of PCE mass is constrained to the first 4–5 m of the subsurface: the concentration of dissolved PCE decreased from over 200 mg l$^{-1}$ at a depth from 2–5 m below the ground surface, to 10 mg l$^{-1}$ at depths larger than 5 m below the ground surface (note that the solubility of PCE is 150 mg l$^{-1}$ at 15°C). As the site is situated in an infiltration area, PCE will migrate further downward after dissolution into the groundwater.

During the installation of the wells for injection, extraction and monitoring, a dye-test was used to characterize the spatial distribution of PCE as NAPL qualitatively. When the dye contacts NAPL it colours red. According to the test, the soil samples from boreholes 1, 32, 42 till 45, 51 till 55 and 61 till 65 contain PCE as NAPL (see Fig. 1 for location of the drillings).

Test set up

An important criteria for a successful application of PITT is that the transmissivity of NAPL-contaminated layer or target layer is large enough to allow the forced flow of
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Fig. 1. Extent of PCE contamination at the site and test layout.
tracers enriched groundwater through the NAPL-contaminated zone. Forced flow of groundwater is necessary to guarantee contact of tracer with the NAPL, to reduce the duration of the test period and to facilitate interpretation of breakthrough curves (by a well known flow field).

To select a site to conduct PITT a site selection procedure was carried out. This involved a review of 32 possible test site locations in the province of Noord-Brabant. A high probability of DNAPL-presence coincided with low transmissivity of the target layer. The Nuenen group, which is abundant in the province of Noord-Brabant, acted as a geological trap for DNAPLs. In fact the first loam layer encountered by the DNAPL is a very efficient trap. At these sites a sandy layer only a few metres thick overlying the loam layer is available for PITT. Furthermore, the phreatic groundwater table proved to be just a few decimetres up to at most 1 m above the loam.

The small saturated thickness of the target layer requires careful design of the system for flushing the NAPL with tracers. Drawdown of the phreatic water table limits the maximum groundwater extraction rate. A system for flushing of the NAPL with tracers was designed, consisting of six groundwater extraction wells—located in a hexagon—and one injection well located at the centre of the hexagon. Figure 1 provides an overview of the contaminant situation and the test layout. Well 1 is used for injection, the six outer wells are used for extraction. The injection rate is equal to the sum of the extraction at the six wells. Due to the distribution of the extraction over six wells, a total of 1 m$^3$ day$^{-1}$ of groundwater can be extracted out of this thin layer without lowering the water table below the well screens.

Over a 60 h period, deoxidised water containing the tracers bromide, isopropanol, 2,4-dimethyl-3-pentanol, and 1-hexanol was injected at an approximately constant rate of 1.15 m$^3$ day$^{-1}$ at initial concentrations of respectively 1000, 3200, 2800 and 2800 mg l$^{-1}$. Injection of the tracers is followed by a period of 60 days in which only deoxidised water is injected (the chaser). During the whole test period 1 m$^3$ day$^{-1}$ of groundwater will be extracted and injected. Breakthrough of the tracers is monitored at 24 monitoring wells placed on six transects between the injection and extraction wells (Fig. 1).

**PRELIMINARY RESULTS**

The injection of tracers started on 19 October 1999. Breakthrough of bromide and the non-conservative tracers at the first ring of monitoring wells (11, 31, 51, Fig. 1) was observed from 20 October until the 27 October (Fig. 2, well 31 not shown). Breakthrough at the second ring of wells (12, 32, 52, Fig. 1 shows location but not breakthrough), started on 23 October. Based on these breakthrough curves, the distance between the monitoring wells and the nature of the flow field, breakthrough of the tracers at the third and fourth ring of monitoring wells was expected on 2 November and 18 November 1999, respectively.

The breakthrough of tracers observed at well 11 shows no effect of retardation or mixing: the centres of mass of the curves for conservative- and non-conservative tracers coincide. Peak concentrations equal the injection concentrations. Tailing of the curves shows the effect of non-equilibrium processes. Peak concentrations at well 51 are less than the injection concentrations. Some mixing must occur, either during
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Fig. 2 Breakthrough curves at monitoring wells 11 and 51.

sampling or in the aquifer itself. The centres of mass of the curves for pentanol and hexanol seem to be retarded by two days compared to the breakthrough of bromide. This might be an indication of NAPL-presence. This compares well to the dye test results for drillings 11 and 51: according to the indicator no NAPL is present at well 11, but is at well 51.

At the end of the test when breakthrough has been observed at all wells, inverse modelling is expected to show a clear distinction in zones with high PCE NAPL saturation and zones without PCE-NAPLs. Analysis of NAPL saturation of soil samples will enable us to compare the results from the PITT with conventional methods for measuring NAPL saturation. At the time of writing, the field experiment was ongoing.

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REFERENCES


