Dramatic LNAPL recovery at a Ontario manufacturing facility

A state-of-the-art Light Non-Aqueous Phase Liquid (LNAPL) recovery pilot study has been performed at a large manufacturing facility in Cambridge, Ontario. The facility has been in operation for nearly 100 years and is bound by a river to the east, a well field to the north, residential housing to the west, and wetlands to the south. The site is directly underlain by fractured dolostone bedrock (approximately two metres below grade), and the water table is encountered beneath the bedrock surface, approximately 2 to 3 metres below grade, flowing in an easterly direction towards the river.

Environmental studies conducted at the site have identified a zone of LNAPL floating on the water table in the fractures and weathered bedding planes within the dolostone bedrock at different localities on the site. The LNAPL forms a separate layer of free product which floats on the water table in a fashion similar to the oil in a salad dressing when left undisturbed.

Hydrogeological studies at the site have characterized the dolostone bedrock to have an average hydraulic conductivity of 2.5 x 10^{-5} m/s, a porosity of 5-10 %, and a transmissivity of approximately 6 x 10^{-2} m^2/s. The uppermost weathered bedrock zone extends to a depth of 15 metres below grade, and is underlain by a zone of lower permeability dolostone extending from 15 to 25 metres below grade. The municipal aquifer zone extends from 25 to 100 metres below grade in the study area. Given the range of porosity, model predictions estimate LNAPL volumes of 500 to 1,000 L at two separate locations on the site. Significant efforts have been made to remove the LNAPL, and associated dissolved phase plume including the installation of groundwater extraction wells along with monthly manual pumping of LNAPL recovery wells with a diaphragm pump. Pumped groundwater is treated on-site and used as make-up water in the facility. The recovered LNAPL is shipped off-site for disposal at a licensed facility.

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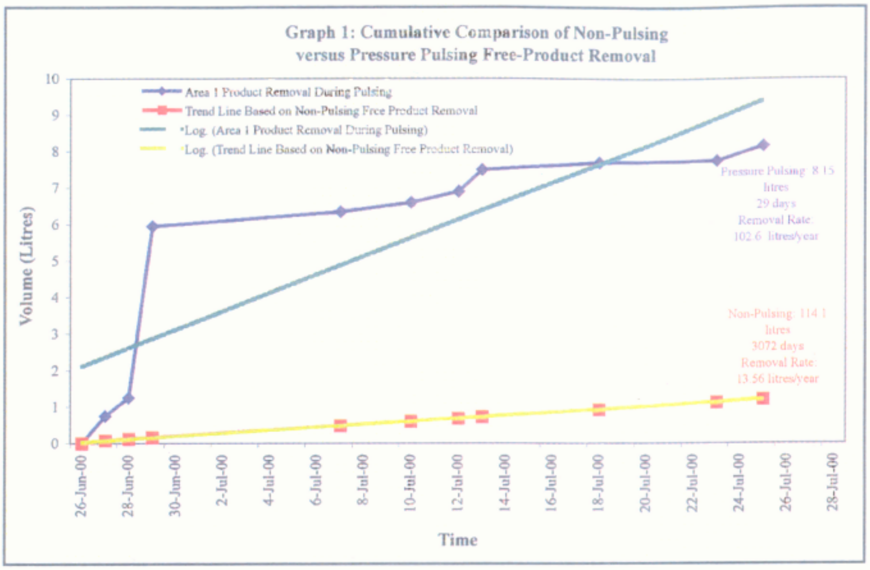
Graph 1: Cumulative Comparison of Non-Pulsing versus Pressure Pulsing Free-Product Removal

The LNAPL, composed of bis (2-ethylhexyl) phthalate – also referred to as di-octyl phthalate (DOP) – has a density of 0.9861 g/cm^3 and viscosity of 150 cp. The LNAPL layer has a measured average thickness of 0.5 cm within the on-site plume, and the historical recovery rate using conventional pump-and-treat technology has been approximately 13.6 litres/year (from the area of the site referred to as Area 1). **See Graph 1.**

From June 1, 2000, to August 25, 2000, a state-of-the-art enhanced LNAPL recovery scheme was employed at Area 1 on the site using a technology developed for, and proven in the oil industry. The technology is referred to as Pressure Pulse Technology (PPT) and was patented by PE-TECH Inc. of Cambridge, Ontario and Edmonton, Alberta.

What is Pressure Pulse Technology?

About 15 years ago, Dr. Tim Spanos at the University of Alberta finished the initial development of a rigorous theory of porous media mechanics. Previous simplifications and assumptions were examined, found wanting, and corrected, resulting in a theory that is more thermodynamically sound than either Darcy theory for non-dynamic flow, or Biot-Gassmann theory for wave propagation. For example, Spanos found that porosity in porous media plays a fundamental role; to be rigorous, it must be

Continued overleaf

Table 1: Pulsing versus Non-Pulsing Recovery Rates and Estimated LNAPL Removal Times

Location	Estimated Free Product Volume (litres)	Historic Free Product Removal Rate (litres/yr)	Pressure Pulsing Free Product Removal Rate (litres/yr)	Estimated Time for Free Product Removal Non-Pulsing (yrs)	Estimated Time for Free Product Removal Pulsing (yrs)
Area 1 (5% porosity)	500	13.6	102.6	36.9	4.9
(10 % Porosity)	1000	13.6	102.6	73.7	9.8

PLATE 1A:
Pulsing Data for OWA

treated as a thermodynamic state variable, similar to pressure and temperature, and not as a dynamically invariant quantity. (Aspects are discussed in the Dec'99 and Apr'00 issues of the *Journal of Canadian Petroleum Technology* and at www.geoservicegroup.com).

Based on Spanos' work, PPT was developed into two basic modes: an oil well workover mode; and, a field-wide excitation mode. The first mode is the use of aggressive pressure pulsing to establish oil production in new wells, or to revitalize flow from older wells that may have experienced flow declines as the result of near-wellbore blockages, disconnection from reservoir energy sources, or other reasons. The second mode is the use of long-term pressure pulsing in specific excitation wells to enhance the liquid mobility in the reservoir so that adjacent wells can experience increases in production.

There remain a number of areas outside the oil sector where PPT can, and is being applied to yield both technical and financial benefits. In fact, the types of problems incurred in the environmental industry are physically quite similar to those encountered in the petroleum industry, except for two major factors: the pressures are much lower because of the shallow burial, and there is often a phreatic interface close to or within the aquifer. Applications of PPT in the environmental industry include:

1. Mobilizing LNAPLs and Dense Non-Aqueous Phase Liquids (DNAPL).
2. Introduction of bioactive agents and nutrients in a well-dispersed manner.
3. Stabilizing viscous fingering or permeability channeling.
4. Increasing the basic flow rate so as to shorten any clean-up activity.
5. Unplugging blocked water wells through mechanical perturbation effects of PPT.
6. Purge aquifers of saline water encroachment through excessive pumping.
7. Reduce the blockage rate of filtration beds (i.e. iron walls).
8. Deep well disposal of liquid dominated slurries such as feedlot wastes.

PPT Project Study Experience

At the site, PPT was used to produce pulses of pressure at the water table (approximately 2.5 metres depth), and has been shown to have the positive effects of increasing water levels, increasing LNAPL thickness, and increasing LNAPL recovery rates in the monitoring and recovery wells.

The effects of PPT at the site include an average water level increase of up to 1.0 metre, and an increased LNAPL thickness of 0.5 cm to in excess of 50.0 cm in monitoring wells on-site. **Plates 1A and 1B** display the effects of PPT at monitoring well OWA. Recovery rates of LNAPL have also increased from 13.6 L/year to about 102 L/year. **(See Graph 1).**

Table 1 provides a summary of non-pulsing versus pressure pulsing recovery rates and associated volumes, along with projected time periods for LNAPL free product recovery from Area 1 on the site.

Summary

In summary, PPT has had a direct impact at the site, including an increased water level in the vicinity of the pulsing well by as much as 1.0 metre, an increased LNAPL thickness ranging from 300 to more than 1,000%, and increased LNAPL recovery rates up to 7.5 times faster than non-pulsing recovery rates. Data analysis indicates that, at current non-pulsing recovery rates, free product removal will require about 37-74 years of continued pump and treat using conventional technology for LNAPL volumes of 500 litres and 1,000 litres respectively (accounting for a range in porosity from 5-10%).

Conversely, for enhanced LNAPL recovery using PPT, recovery rates for free product removal will be reduced to about 5-10 years of continued enhanced pump and treat for LNAPL volumes of 500 litres and 1,000 litres respectively. The magnitude of both the financial and environmental implications for overall site remediation can be clearly drawn from these results.

For more information, circle reply card No. 115

PLATE 1B:
Product Thickness in Meters for OWA