

ECONOMIC EVALUATION OF LONG-TERM PUMP AND TREAT VERSUS IN SITU CHEMICAL OXIDATION

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ABSTRACT: An economic evaluation was performed to compare the costs of treating groundwater using in situ chemical oxidation as an alternative to long-term pump and treat technology. Pump and treat systems typically have a common problem in that the contaminant concentrations reach an asymptotic level (tailing effect) after several years of operation and continued operation becomes inefficient and costly. A cost evaluation was performed for three groundwater pump and treat sites in California. At two of the sites, the pump and treat system was terminated after several years of operation in favor of chemical oxidation treatment as a means of expediting the timeframe to achieve risk-based groundwater cleanup levels. Chemical oxidation treatment was performed using two types of oxidants: potassium permanganate and Fenton's oxidation. The costs for chemical oxidation treatment varied from a low of \$305,000 for potassium permanganate to a high of \$360,000 for Fenton's oxidation treatment. The chemical oxidation treatment costs at these two sites are believed to be typical of most groundwater sites, although actual costs will vary somewhat depending on site conditions. Based on this evaluation, the cost to cleanup groundwater using in situ chemical oxidation can typically be paid for in as little as one to two years of continuing with pump and treat.

INTRODUCTION

Conventional treatment on the majority of the contaminated groundwater sites in the U.S. is by pump and treat technology. Groundwater pump and treat has been chosen as the preferred technology on over 68% of federal Superfund sites, a majority of RCRA groundwater sites, and at most leaking UST sites throughout the U.S. (U.S. EPA 1996). In recent years, innovative treatment alternatives, such as in situ chemical oxidation, have begun to gain regulatory acceptance, as evidenced by approximately 15 percent of Superfund sites approving pump and treat coupled with in situ remediation (EPA 2001a).

Pump and treat is normally very effective in containing the off-site migration of the groundwater plume and in quickly reducing elevated contaminant levels. However, most pump and treat systems have a similar problem in that the dissolved concentrations reach an asymptotic level after several years of operation. This so-called "tailing effect" has been described in detail by several authors (Cohen, et al 1997 and Palmer, et al 1992). The remaining levels of contaminants after five years of pump and treat are commonly at levels above risk-based groundwater action levels and do not allow for closure of the site. This is especially true for sites contaminated with hydrophobic compounds such as trichloroethylene (TCE), tetrachloroethylene (PCE), and other recalcitrant constituents. Typical operational timeframes for pump and treat systems range from 5 to 15 years for privately-funded industrial site cleanups. The cleanup timeframe for federal Superfund sites often extends to 20 to 30 years (EPA 2001b).

In this paper, long-term groundwater pump and treat systems at three industrial sites in California were evaluated for cost comparison purposes. The annual costs for continuing operation of each system was then compared to chemical oxidation treatment. This type of economic evaluation is often useful for corporate environmental managers in determining whether there is a financial benefit in discontinuing a long-term pump and treatment system in favor of a more cost effective treatment.

Description of Site No. 1. This site is an industrial facility located in La Mirada, CA. This site is a moderately large facility (over 2 acres in size), with seven groundwater extraction wells (pumping a combined 15 gallons per minute (gpm)) and 31 groundwater monitoring wells. The plume size measured approximately 180 feet long by 120 feet wide. As of June 2002, the groundwater treatment system had pumped and treated over 32 million gallons of groundwater (which is equivalent to approximately 50 pore volumes). The groundwater is treated in six-1,000 pound carbon canisters which are arranged in two parallel lines of three canisters each.

The groundwater pump and treatment system has operated at Site No. 1 for six years for the removal of TCE. Using pump and treat, initial TCE concentrations over 9,000 micrograms per liter (ug/l) were reduced to a level of about 400 to 500 ug/l (total influent concentration) within three years of operation. However, the TCE influent concentrations began to plateau at the 400-500 ug/l level starting after the fourth year of operation and continued over the last 30 months of system operation. A graph illustrating the asymptotic levels reached after several years of pump and treat is shown in Figure 1.

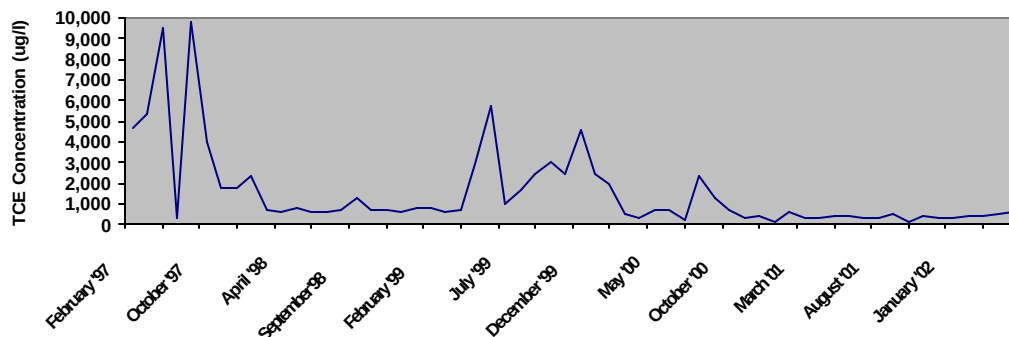


FIGURE 1. Influent TCE levels for pump and treat system at Site No.1.

In the first four years of operation (through February 2001) at Site No. 1, the pump and treat system removed an estimated total of 356 pounds of volatile organic constituents (VOCs). In comparison, over the last 18 months, the pump and treat system has removed only 23 pounds of VOCs. At the current rate of decline, it is estimated that it may take another six years (or more) to reach the groundwater action level for TCE (less than 50 ug/l). The groundwater pumping rate has not varied significantly over the five and one-half year history of groundwater treatment. The groundwater treatment system has maintained an uptime of over 95 percent.

Description of Site No. 2. This site is an industrial facility located in Rancho Dominguez, CA. This is a medium sized site, with two groundwater extraction wells (pumping an

The groundwater pump and treatment system has operated at Site No. 2 for five years for the removal of methylene chloride (MeCl). Initial MeCl concentrations over 2,600,000 ug/l were rapidly reduced using pump and treat technology. However, the influent MeCl concentrations began to plateau at 500-800 ppb level starting after the fourth year of operation. The asymptotic level of about 500-800 ppb has continued over the last 18 months of system operation. A graph illustrating the tailing effect after several years of pump and treat is shown in Figure 2.



COST ANALYSIS OF PUMP AND TREAT

The major cost items for operation and maintenance (O&M) of the three pump and treat systems included routine activities such as O&M field labor, equipment repairs/replacements, spent carbon change-outs, quarterly NPDES sampling, and semi-annual groundwater sampling, and project management/reporting. The costs reported in this paper are based on actual invoiced costs that have been averaged on a yearly basis. The

average annual O&M cost for Site No. 1 pump treat system was determined to be approximately \$216,000. The annual cost for Site No.2 was estimated to be \$110,000. The annual cost for O&M at Site No. 3 is estimated as \$97,200.

A cost summary of three groundwater pump and treat systems is provided in Table 1 below. For comparison purposes, the median pump and treat cost (\$350,000) at Superfund sites is also provided. Cost data was compiled on 88 EPA Superfund sites across the country (EPA 2001b) and ranged from a low of \$36,000 to a high of over \$4 million per year. Note that only 18% of the Superfund sites have made at least 80 percent progress towards groundwater restoration goals (EPA 2001b). Many pump and treat systems have been operated for 15 to 20 years without achieving groundwater cleanup goals (including privately-funded industrial sites), while remediation engineers continue to use a 20-year duration for cost analysis of pump and treat systems.

TABLE 1. Cost summary for pump and treat systems

Item	Site No. 1 Average Annual Cost	Site No.2 Average Annual Cost	Site No. 3 Average Annual Cost	Superfund Site Median Annual Cost (EPA 2001b)
O&M Field Labor	\$98,400	\$ 32,400	30,000	Not Provided
Project Management and Report Preparation	\$64,800	\$ 37,200	35,100	Not Provided
Laboratory Fees (Groundwater sampling and NPDES monitoring)	\$31,200	\$ 20,000	20,800	Not Provided
Carbon Change-outs	\$8,400	\$ 7,600	2,800	Not Provided
Equipment Repairs and Miscellaneous	\$13,200	\$ 13,200	8,500	Not Provided
Totals	\$216,000	\$ 110,400	\$97,200	\$350,000
Cost per Cubic Yard of Treatment	\$17	\$69	\$21	Not Provided

The cost per cubic yard of treatment zone was also calculated for the three pump and treat systems and are provided in Table 1. The cost per cubic yard varied from a low of \$17 per yard (for site No. 1) to a high of \$69 per yard (for site No. 2). The wide range of values indicates that the cost of pump and treat is more dependent upon on contaminant mass than treatment volume. It also indicates that pump and treat is more efficient on large plumes (large volume sites).

Note that the above pump and treat costs do not include utility costs. Utility costs (primarily electricity) for a conventional carbon adsorption treatment system is typically not a large cost item, with approximate fees of less than \$300 per month. Electricity consumption by catalytic oxidizers can be much more expensive than carbon treatment, but this cost factor was not considered in this cost analysis.

COST EFFICIENCY EVALUATION

The unit cost of removing a pound of contaminant over the life of the pump and treat system was performed. This determination provided a cost efficiency factor of the pump and treat system which could be used in comparison to chemical oxidation

technologies. An evaluation of Site No.1 determined that the cost per pound of contaminant removal was in the range of \$2,000 to \$6,300 over the first four years of operation. However, starting at year 5, the unit rose to \$12,000. In Year 6 the unit cost of contaminant removal rose to \$30,000 and the projected unit cost for year 7 will be more than \$60,000. A graph illustrating the increasing cost of pump and treat with years of operation is provided in Figure 3.

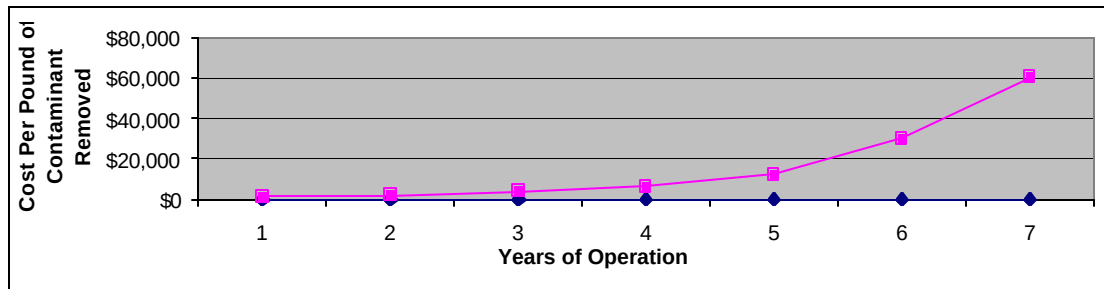


FIGURE 3. Cost efficiency determination for pump and treat.

COST ANALYSIS OF CHEMICAL OXIDATION TREATMENT

Chemical oxidation treatment was completed at Sites No. 1 and 3 following pump and treat operation. The costs associated with implementing chemical oxidation at these sites is compared in Table 2 below. Starting in early 2002, an in situ chemical oxidation pilot study using potassium permanganate (KMnO_4) was completed at Site No. 1. The cost to implement the pilot study and the full-scale treatment over the entire site is estimated at \$305,000. Thus, the cost to cleanup Site No. 1 using KMnO_4 can be paid for in approximately 1.5 years of continuing with the pump and treat system. Chemical oxidation provides a significant cost savings over the normal life of a pump and treat system.

In June 2003, Fenton's oxidation treatment was conducted at Site No.3. Twenty-one application wells were installed at this site to treat an off-site gasoline plume which extended 150 feet down-gradient of the site. Over the course of the four-week injection period, a total of approximately 8,600 gallons of hydrogen peroxide were injected in the groundwater at this site. The cost to implement the Fenton's treatment at Site No. 3 was approximately \$360,000. The cost to cleanup Site No. 3 using Fenton's oxidation can be paid for in approximately three years of continuing with the pump and treat system. The actual payback period is much less than three years, since the pump and treat system

TABLE 2. Cost comparison of chemical oxidation treatment technologies.

Cost Item	Potassium Permanganate Treatment at Site No. 1	Fenton's Reagent Treatment at Site No. 3
Bench Scale Test	\$ 15,000	10,000
Field Labor	\$ 65,000	130,000
Project Management, Workplan, and Report Preparation	\$ 85,000	85,000
Laboratory Fees (groundwater sampling)	\$ 95,000	85,000
Chemical Costs, Equipment, and Miscellaneous Expenses	\$ 45,000	50,000
Total Costs	\$ 305,000	360,000

would need to be expanded (at additional capital cost not included in this analysis) in order to capture the down-gradient plume.

The costs associated with chemical oxidation treatment are typically incurred within a short time frame of 6-12 months. For the purposes of this study, the chemical oxidation costs include both the pilot study and full-scale implementation cost. The major cost items involved in chemical oxidation treatment are summarized in Table 2. Over 30 percent of the total costs of chemical oxidation treatment is typically comprised of lab fees associated with the groundwater monitoring program. The total costs of chemical oxidation treatment detailed above are representative costs for medium to moderately large sites.

The unit cost per pound of contaminant removed by chemical oxidation at Sites No. 1 and 3 was calculated to compare with the pump and treat unit cost. The Fenton's treatment showed a low unit cost of less than \$100 per pound, whereas potassium permanganate showed a unit cost of about \$3,000 per pound. Note that the Fenton's unit cost is much lower than potassium permanganate because more contaminant mass was available for removal at Site No. 3. When compared to pump and treat (unit cost of \$6,000 to 30,000 per pound), the unit costs of both chemical oxidation technologies prove to be substantially lower.

DISCUSSION AND CONCLUSIONS

The cost to clean up Site No. 1 site using KMnO_4 (\$305,000) can be fully recovered in 1.5 years of continuing with operation of the pump and treat system (@\$216,000 per year). Similarly, at Site No.3 the Fenton's treatment costs (\$360,000) can be recovered within two to three years. Thus, chemical oxidation is a cost-effective alternative to pump and treat. Although other investigators have claimed that Fenton's treatment may not be cost-effective in achieving the low groundwater action levels required to obtain closure of the site (Shiple et al, 2002), this study concludes that Fenton's and other chemical oxidation technologies are cost-effective and highly successful as a "polishing" technology. The Fenton's results indicate that chemical oxidation can be equally cost-effective when used as a "hot spot" treatment method.

The greatest economic value of chemical oxidation treatment is the potential long-term cost savings. For example, it has been estimated that the Site No. 1 pump and treat system would need to operate for another 6 years or more to achieve groundwater cleanup levels. Based on this projection, a potential cost savings of over one million dollars could be realized at Site No.1 (over 6 years). Similar cost savings can be derived at other VOC contaminated sites, although the actual savings are highly site dependent.

Although the chemical oxidation costs for the two sites discussed in this paper are considered typical for moderate sized plumes, there is an occasional site at which much greater costs can be incurred when implementing chemical oxidation. For example, at a site in Northern California, a large PCE plume extended several blocks down-gradient from the source area. Chemical oxidation treatment at this site has been estimated to be over one million dollars due the depth to groundwater (over 60 feet), the fact that most of the plume extended offsite, and the many injections wells (or re-circulation wells) that would be needed.

A number of factors may influence the effectiveness and the ultimate costs of chemical oxidation treatment.

- Permeability of the aquifer (fine grained sediments retard flow and dispersion of oxidant) and depth to groundwater.
- Dissolved total organic carbon levels (high TOC requires more treatment)
- Geochemical makeup of sediments (high soil oxidant demand requires more treatment)
- Dissolved and Sorbed VOC Levels (higher VOCs require more chemical treatment)
- Size of the VOC Plume
- Type of VOC (KMnO_4 works best on chlorinated ethenes, while Fenton's and Ozone work on nearly all organics)

The chemical oxidation treatment costs would be slightly higher for sites with higher VOC concentrations or for sites with a larger more widespread plume than the examples given here. Also, sites with finer grained sediments and sites with higher dissolved organic levels may require more costs to cleanup than presented here.

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