Mitigation Of Vapor Intrusion By Chlorinated Solvents Using Bioremediation Products At A Site In York, Pa: A Case Study

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This Paper describes studies carried out at a site in York, PA that operated a dry-cleaning facility between 1956 and 1970. Presence of chlorinated solvents including Trichloroethelyne (TCE) and Tetrachloroethylene (PCE) was recorded for the first time in the soil in 2012 and the incidence of Vapor Intrusion (VI) was recorded later in 2016 as part sub-slab soil gas analysis by a previous consultant. In June 2017, our team partnered with the property owner of the facility to participate in mitigating vapor intrusion and to make the indoor air safe for the occupants. A remedial action plan was submitted to PA DEP and after their approval, it was decided to evaluate the effectiveness of VaporRemed, a bioremediation product, to mitigate the VI. VaporRemed has been successfully used extensively for the mitigation of fuel oil odors, however, this is first time that VaporRemed was used for mitigating vapor intrusion by chlorinated hydrocarbons. Indoor air data was collected for a period of 20 months to study the effect of VaporRemed on the source of the contamination and vapor intrusion. Effect of VaporRemed on three primary chemicals of concern namely Tetrachloroethene (PCE), Trichloroethene (TCE), and cis 1,2-dichloroethene (DCE) has been selected for evaluation. The results show that VaporRemed effectively reduces chlorinated hydrocarbons in a significantly short period as seen from the rate of decay. The data on the analyses of indoor air in various rooms also show the values of these compounds are reduced to meet the stipulated by the PA DEP. VaporRemed is seen to improve the efficiency of institutional controls and thus reduce the cost of cleanup.

1 Introduction

The site under investigation is a strip mall in York, PA. A portion of the site was leased to a dry cleaning facility between 1956 and 1990. The mall today has many stores in its three levels including the basement, the first floor, rooms in the rearside of the mall, and the front shops. The contamination of the site with toxic chemicals such as Tetrachloroehene (PCE), Trichloroethene (TCE), and other breakdown products was first recorded in the soil in 2012. A list of the past environmental investigations is presented below:

- In August 2011, the first environmental Phase II investigation was carried out wherein soil core samples were analyzed and these showed higher (greater than the site specific limits) values of TCE and PCE.
- In July 2012, another consultant recorded the levels of contamination in groundwater at the site and reported elevated values of chlorinated hydrocarbons at some of the groundwater samples.
- In December 2014, one more groundwater sampling event was carried out by another Environmental consultant confirming the results recorded in 2012.
- In January 2016, one more Environmental Consultant who in addition to groundwater and soil sampling conducted soil gas sampling for the first time.

1.1 Enhanced Aerobic Bioremediation - An introduction

In their report in July 2000, the US EPA had examined engineered approaches to in situ remediation focusing mostly on anaerobic bioremediation. Studies on bioremediation of chlorinated hydrocarbons are mostly for degradation by anaerobic bacteria in groundwater as in those studies, vapor intrusion is through groundwater where these compounds are normally located in anoxic conditions.

In the present investigation, the vapor intrusion does not appear to be originating from groundwater and the source of contamination is either soil or sub-slab areas and near-source soil gas points. It was therefore decided to evaluate the VaporRemed as conditions were aerobic. Our group reached out to the owner of the property and entered into a contract to evaluate the bioremediation of the site using our own resources. The project was started in early 2017 and was to be completed by June 30, 2020. The project was carried out with approval from the PA DEP at every stage both onsite consultation and consultation in their office. The project was carried out in the following four phases.

- Enhanced bioremediation of contaminated soil
- Sub-slab gas sampling and remediation with VaporRemed
- Monitoring Vapor Intrusion before and after treatment with VaporRemed
- Near source soil gas analysis and bioremediation of impacted sites.

1.1.1 Bioremediation of soils contaminated with chlorinated solvents

Soil samples were collected from locations based on the characterization carried out by earlier investigators. The soil was collected using geoprobe and the core samples were packed for shipment to the laboratory analyses. The same geoprobe was used for introducing the bioremediation product. Soil bore samples at one sampling location showed elevated values of three chemicals of concern before introducing bioremediation products. The soil was sampled again after one month and the values were compared. The results are shown in Table 1. It is seen that both Tetrachloroethene (PCE)

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and Trichloroethene (TCE) showed 99.9% and 97.9% reduction after 71 days as a result of bioremediation.

1.1.1.1 First-order decay formula used throughout the report

Definition : A quantity is subject to exponential decay if it decreases at a rate proportional to its current value. In this report and the attached source code, we are using the following formula.

$$rate = (24 * 3600) * (\ln r2 - \ln r1)/timeInSeconds \quad (1)$$

where *timeInSeconds* is difference in time in seconds, *r1* is the contamination level at time T1, *r2* is the contamination level at time T2.

It is clear from this decay rate that PCE reached the site-specific levels of 22 ppm (22,000 ppb) in the soil in 35 days with one single application of VaporRemed. In the same manner, TCE values were also reduced to the site-specific levels almost at the same time in the soil. The formula given above does not apply to the other two compounds as there was no decay, rather an increase in these levels. The results confirm that aerobic remediation of both PCE and TCE in conjunction with increase in levels of cis12DCE and VC as is consistent with such remediation occurred at the site.

2 Bioremediation of sub-slab source of contamination

The significant reduction in the level of contamination in the soil was presented to DEP at their visit to the site. DEP advised that the study should now focus on the indoor air.

It was decided to monitor the values of PCE and TCE in the sub-slab sampling point VP 3. The values in the sub-slab locations showed similar high values of PCE as was reported earlier in 2016. VP 3 was therefore selected as the primary location for bioremediation and mitigation of the contaminants. The sampling point VP 3 is located in the mechanical room in the basement closer to a 300-gallon concrete basin for collecting wastewater.

One more sub-slab sampling point EPS 1 was installed on the opposite end of the basement below the warehouse where the soil showed contamination with the chlorinated hydrocarbons. Comparative values of sub-slab air are given in Table 2 below. The results showed that VP 3 showed very high values of the chemicals compared to EPS 1 located directly below the contaminated soil. Therefore, VP 3 was selected as the prime source of Vapor Intrusion.

2.1 Tables

.	DCE		PCE		TCE	
Date	**VP3**	**EPS1**	**VP3**	**EPS1**	VP3	**EPS1**
2/21/2018	23,000	350	107,000	876.00	7,700.00	107.00
5/17/2018	92,700	259	103,000	4112.00	9,750	84.6

Table 2 Monitoring sub-slab surfaces in VP 3 and EPS 1

Mitigation of the chemicals of concern at the sub-slab source VP 3 through bioremediation was examined using VaporRemed. In the following table, values of PCE, TCE, and DCE were monitored after the addition of VaporRemed before, 2 hours after the addition of VaporRemed, and 24 hours after the addition of VaporRemed. Table 3 below shows the values recorded on three different occasions.

Location Id	Collection Date Time	Analyte	Result	Units
VP-3 (Before)	07/25/2018 09:00	Tetrachloroethene	55600	ug/m3
VP-3 (After)	07/25/2018 11:00	Tetrachloroethene	28400	ug/m3
VP-3 (Before)	07/25/2018 09:00	Trichloroethene	21900	ug/m3
VP-3 (After)	07/25/2018 11:00	Trichloroethene	11600	ug/m3
VP-3	3/4/2016 09:00	Tetrachloroethene	110000	ug/m3
VP-3	2/21/2018 09:00	Tetrachloroethene	107000	ug/m3
VP-3	5/17/2018 09:00	Tetrachloroethene	110000	ug/m3
VP-3	6/21/2018 09:00	Tetrachloroethene	32000	ug/m3
VP-3	7/25/2018 09:00	Tetrachloroethene	55000	ug/m3
VP-3	8/28/2018 09:00	Tetrachloroethene	15500	ug/m3
VP-3	3/4/2016 09:00	Trichloroethene	7300	ug/m3
VP-3	2/21/2018 09:00	Trichloroethene	7710	ug/m3
VP-3	5/17/2018 09:00	Trichloroethene	9750	ug/m3
VP-3	6/21/2018 09:00	Trichloroethene	15500	ug/m3
VP-3	7/25/2018 09:00	Trichloroethene	21500	ug/m3
VP-3	8/28/2018 09:00	Trichloroethene	11500	ug/m3
VP-3	3/4/2016 09:00	"cis-1,2-Dichloroethene"	32000	ug/m3
VP-3	2/21/2018 09:00	"cis-1,2-Dichloroethene"	23300	ug/m3
VP-3	5/17/2018 09:00	"cis-1,2-Dichloroethene"	92700	ug/m3
VP-3	6/21/2018 09:00	"cis-1,2-Dichloroethene"	434000	ug/m3
VP-3	7/25/2018 09:00	"cis-1,2-Dichloroethene"	86500	ug/m3
VP-3	8/28/2018 09:00	"cis-1,2-Dichloroethene"	147000	ug/m3

Table 3 Values of PCE, TCE, and DCE before and after addition of VaporRemed

3 Bacterial Counts

It is seen from the above table, that there is a consistent reduction of both PCE and TCE after the addition of VaporRemed. The value of DCE, on the other hand, showed a significant increase. This suggests the degradation of both PCE and TCE into DCE as has been proposed in available literature. The rate of decay was computed based on the values recorded above for the effect of VaporRemed on PCE and TCE. The rst order decay rate for PCE and TCE was calculated for data on 7/25/2018. The same formula given above for decay in soil was applied for the calculation of decay here. PCE showed a decay rate of -800 % while the rate of decay for TCE was -762 %. The results show that VaporRemed is effective in mitigating the contamination is the sub-slab application.

It was decided to determine if either PCE or TCE was toxic to the aerobic bacteria in VaporRemed by taking bacterial counts in VP-3 between Mar 23rd and Mar 25th, 2020. A sustained population count indicates that the bacteria were able to utilize either PCE or TCE or both. It also confirms that the conditions were not anoxic.

- Bacterial count after 2 hours: 14, 800, 000 CFU/ml
- Bacterial count after 72 hours : 15,300, 000 CFU/ml

The sustained population count indicates that the conditions at VP-003 and that PCE and TCE were not toxic to the bacteria in VaporRemed. The fact that the bacterial population was at sustained levels indicated that the conditions in the sub-slab soil-gas location were not anaerobic and supported aerobic bioremediation.

4 Monitoring indoor air for vapor intrusion

Earlier studies by other environmental companies generally restricted with delineation of soil and groundwater contaminations. Their studies did not include indoor air monitoring. Since TCE is known to be a carcinogenic, we believed that it was important to monitor TCE, PCE levels in indoor air. Prior to the present study, only once in 2016 was the indoor air levels measured in

Table 1 Contamination levels at Soil Bore 121

Date	PCE	Pct. Reduction in PCE	TCE	Pct. Reduction in TCE	DCE	Pct. Increase in DCE	VC	Pct. Increase in VC
6/28/2017	2680	n/a	7.4	n/a	3.7	n/a	0.047	n/a
9/11/2017	0.73	99.99	0.15	99.97	83.9	2167.63	10.7	2127.7

VP 3 and the data showed that the values of PCE and TCE showed exceedances in VP 3. However, there was no follow up action. During the one of our meetings with the DEP, it was suggested that we focus on the evaluation of sub-slab gas monitoring and also record the values in different rooms in the facility. These rooms are listed below.

- IA 001: Basement: Just outside VP 3 sub-slab sampling point.
- IA 002: Basement: the Middle room in the basement away from VP 3
- IA 003: Basement: Just below the warehouse and the loading dock
- IA 004: H Block closer to the rear parking lot away from VP 3
- IA 005: Restroom away from VP 3
- IA 006: A room identied as a Vault away from VP 3
- IA 007: Yoga room In the line of VP 3
- IA 008: WIS oce in the line of VP 3
- IA 009: Ambient air on top of the warehouse away from VP 3
- IA 010: Store in the front D Block: Jewelry store away from VP 3
- IA 011: Store in the front C block away from VP 3
- IA 012: Store in Front C block away from VP 3

Indoor air in the basement was selected as the primary indicator of indoor air contamination. Thus, the sampling point IA 001 was selected to detect the changes after adding VaporRemed to VP 3. IA 001 was also closest to VP 3 which was already identified as a location of concern. The results are presented below.

5 Contamination levels at IA 001

Date	Location	PCE	TCE	DCE	VC
04/06/2018 08:35	IA-001	121.000000	7.800000	12.500000	0.470000
05/17/2018 09:00	IA-001	288.000000	21.000000	61.800000	0.470000
06/21/2018 09:00	IA-001	719.000000	97.800000	222.000000	4.500000
07/18/2018 09:00	IA-001	754.000000	54.100000	97.000000	0.470000
10/03/2018 16:15	IA-001	861.000000	41.900000	395.000000	7.000000
10/23/2018 16:10	IA-001	262.000000	13.800000	72.300000	3.200000
10/24/2018 16:00	IA-001	169.000000	8.700000	47.000000	1.900000
12/06/2018 09:00	IA-001	187.000000	11.200000	45.80000	0.540000
02/25/2019 09:00	IA-001	72.000000	3.300000	15.300000	0.470000
04/04/2019 09:00	IA-001	188.000000	9.300000	38.900000	0.640000
04/18/2019 09:00	IA-001	273.000000	11.200000	57.600000	0.470000
07/24/2019 09:00	IA-001	700.000000	26.800000	86.50000	0.470000
09/23/2019 09:00	IA-001	1240.000000	14.800000	55.600000	0.470000
09/24/2019 09:00	IA-001	1050.000000	12.900000	49.100000	0.470000
09/24/2019 17:00	IA-001	1050.000000	12.900000	49.100000	0.470000
09/25/2019 09:00	IA-001	939.000000	12.500000	44.400000	0.470000
09/25/2019 17:00	IA-001	939.000000	12.500000	44.400000	0.470000
11/13/2019 16:30	IA-001	257.000000	5.200000	15.100000	0.470000
11/14/2019 16:30	IA-001	360.000000	6.900000	20.600000	0.470000
11/18/2019 08:30	IA-001	232.000000	3.600000	15.300000	0.470000
12/12/2019 17:00	IA-001	180.000000	2.500000	10.30000	0.470000
12/19/2019 17:00	IA-001	123.000000	10.00000	8.200000	0.470000
12/26/2019 17:00	IA-001	102.000000	1.800000	7.900000	0.470000
01/17/2020 16:15	IA-001	66.700000	1.200000	5.500000	0.470000
01/30/2020 16:30	IA-001	99.500000	2.10000	7.100000	0.470000
03/02/2020 05:15	IA-001	186.000000	3.400000	14.500000	0.470000

Table 4 Values of PCE, TCE, and DCE before and after addition of VaporRemed

It is seen from the table above that the indoor air in the sampling point IA 001 is less than site-specific limit (SSL) on many events. It is seen that vinyl chloride in indoor air was non-detect.

6 Enhanced Aerobic Bioremediation of Near source contaminated sub-soils

The next step was to delineate sub-soil soil gas to identify additional sources of contamination contributing to the existing levels of contamination as agreed with the DEP. The following six (6) sampling locations based on their significance.

- SG 101: Near the boundary wall of an upgradient property.
- SG 102: Near the boundary of a neighboring downgradient property
- SG 103: Near the boundary of another neighboring residential property
- SG 104: Near the boundary of the neighboring downgradient industrial unit
- SG 105: Near the boundary of another downgradient industrial unit
- SG 106: Close to the wall of the warehouse of the facility

The initial values of the chlorinated hydrocarbons recorded at these six near-source soil-gas locations are presented below:

Date	Sample	PCE(in ppb)	TCE (in ppb)	DCE (in ppb
6/18/2019	SG 101	29,000	7,280	82,700
6/18/2019	SG 102	486	15.1	29.6
6/18/2019	SG 103	5,180	44.4	10.5
6/18/2019	SG 104	102, 000	322	ND
6/18/2019	SG 105	609	31.1	ND
6/18/2019	SG 106	1, 570, 000	332,000	848

Both SG 101 and SG 106 are located on the down gradient side and these points showed high values for PCE, TCE, and DCE. The values recorded for SG 102 and SG 103 indicated that these compounds do not migrate from the current property. Our hypothesis was that SG 101 and SG 106 are likely locations contributing to the indoor air contamination in the facility. It was therefore decided to conduct aerobic bioremediation by introducing VaporRemed at SG 101 and SG 106.

Three additional injection points were installed in a triangular fashion around both SG 101 and SG 106. VaporRemed was added directly from 1-gallon jug into each of the injection points. Table 17 shows the comparative values of PCE, TCE, and DCE before and after the addition of VaporRemed. Table 17 shows the values of these contaminants in soil gas and is compared with the values of indoor air at IA 001. VaporRemed is again effective in mitigating the three contaminants in soil gas. This in turn is reflected in the values of the three contaminants in the indoor air. The values of both PCE and TCE are recorded below the Site-Specific Levels stipulated by PA DEP.

Date	Sample	PCE (in ppb)	TCE (in ppb)	DCE (in ppb)
6/18/2019	SG 101	29,000	7280	82,700
12/12/2019	SG 101	2870	666	2160
12/26/2019	SG 101	3700	911	4490
1/30/2020	SG 101	2340	680	4500
5/11/2020	SG 101	923	1330	48,800
6/18/2019	SG 106	1,570, 000	332, 000	848,000
12/12/2019	SG 106	80,000	336,000	166,000
12/26/2019	SG 106	30,700	70, 400	302,000
1/30/2020	SG 106	10, 700	3,160	248,000
5/11/2020	SG 106	53,600	19,200	157,000
6/18/2019	IA 001	na	na	na
12/12/2019	IA 001	180	2.5	10.3
12/26/2019	IA 001	102	1.8	7.9
1/30/2020	IA 001	99.5	2.1	7.1
5/11/2020	IA 001	159	3.5	14.3

The addition of VaporRemed was stopped after 1/30/2020 and the next sampling was carried out in May to confirm whether VaporRemed was still effective after 5 months. There was an appreciable increase in the three contaminants at SG 106 but much lower than the value recorded before the addition of VaporRemed. It is interesting to note that the value of the three contaminants remained below the SSL in the indoor air. The data suggests that the contamination in VP 3 has a direct bearing to the contamination levels in SG 106. It was not possible to monitor the values in VP 3 as the sub-slab area was full of water due to heavy rains experienced earlier. Also, our objective as defined by the DEP was to monitor and control the values in the indoor air was achieved.

7 Conclusion

- VaporRemed has demonstrated enhanced aerobic bioremediation of chlorinated hydrocarbons in soil and sub-slab areas.
- VaporRemed has reduced the concentration of PCE and TCE in soil gas at location SG 106.
- The results show that SG 106 appears to be the active source of the contamination in the sub-slab sampling point VP 3.
- It is recommended that VaporRemed be considered to enhance the bioremediation of these contaminants and to reduce the cost of cleanup.

Acknowledgments

We would like to thank the following for their support in this project.

- The property owner (name redacted for the purposes of this paper.)
- Kathleen G. Horvath, PG, Section Chief, PA DEP (Retired)
- Ryan J. Carr, PG, Licensed Professional Geologist, PA DEP

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