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IDENTIFICATION AND QUANTIFICATION OF SPECIFIC VOLATILE ORGANIC COMPOUNDS FROM A DRINKING-WATER WELL IN THE UNITED STATES

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Abstract: Volatile Organic Compounds (VOCs) are hazardous to human health and the environment. Because VOCs are dangerous, there is often a requirement to monitor their concentrations; however, current VOC monitoring techniques (spot sampling) are often insufficient to determine their representative concentrations. In this study we used a more representative approach to measured and analyse aggregate concentrations of VOC and their individual components at a Drinking-water Well in the U.S. Continuous measurement of aggregate concentrations of VOC was conducted at the site on hourly sampling basis using an in-borehole gas monitor called *Gasclam* whilst a *Tenax TA* sorbent tube incorporated into and to work in parallel with this instrumentation was used to adsorb bulk concentrations of VOCs and subsequently desorbed (for characterisation) using thermal desorption/gas chromatography-mass spectroscopy (TD/GC-MS) technique. A total concentration of 3785ppm and2108ppm was recorded in wells 1 and 2 respectivelyover the monitoring period. The total concentrations of adsorbed VOCs in the site are 2.64 x 10^2 mg/m^3 and 2.42 x 10^2 mg/m^3in wells 1 and 2 respectively. Among the identified VOCs are those considered to be hazardous to health and environment. Although various types of remediation have been done on this site; the result shows they were not effective. Further remediation is therefore recommended.

Keywords: Carcinogens Gasclam, Ozone formation, TD/GC-MS, Tenax TA, VOCs characterization.

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INTRODUCTION

Volatile organic compounds (VOCs) belong to a set of organic compounds whose vapour pressures are high enough to cause them to readily volatilise into the atmosphere conditions (Pankow, 1987; U.S. EPA, 1992). It is the volatility of VOCs that makes them easily susceptible to human inhalation. VOCs are emitted from a number of sources which can either be natural or anthropogenic (Ciganek and Neca, 2008). Natural sources of VOCs include vegetation, forest fires, and animals (Lemieux et al., 2004; Buzcu and Fraser, 2006). The major anthropogenic sources of VOCs are vehicles, the use of solvents and solvent containing products, and industrial and agricultural sources (Fenger, 1999; Schiffman *et al.,* 2001; Klemp *et al.,* 2002; Folsom and Allen, 2005).Although there are more natural sources of VOC emission; in populated and industrialized areas, anthropogenic sources are major contributors to environmental pollution (Guenther *et al.,* 1995). In pore spaces within the vadoze (unsaturated) zones of contaminated soils, VOCs exist as vapour whilst in the vadoze zones they exist as either dense non-aqueous phase liquid (DNAPL) or light non-aqueous phase liquid (LNAPL). Irrespective of the source, VOCs are generally dangerous both to human health (Rowe *et al.,* 2007; Eljarrat and Barcelo, 2003; Guo *et al.,* 2004; IARC, 2004) and the environment (Environmental Quality Management, 2003;

Tillman and Weaver, 2005).There is, therefore, often a requirement to monitor them in their sources such as contaminated lands, and waters as they are often prioritised for re-use. In this study, we measured firstly the bulk concentration of VOCs in the wells with the aid of an in-borehole gas monitor called Gasclam before specifically identifying their components using Thermal Desorption/Gas Chromatography-Mass Spectroscopy (TG/GC-MS). See the methodology section for more information.

Site description

This site was first investigated on November 10th, 1997 after the owner complained that his drinking water had an odd smell. His well was within 7.6 m of the house. The well was drilled in 1981 and is 53 m deep with a delivery rate of 27 plus litres per minute. The first round of water sampling of the well indicated no hydrocarbons. However a sample collected on December 4th, 1997 showed contamination of 44 parts per billion (ppb) and 47 ppb of total hydrocarbons. Bedrock was within 61 cm of the surface. The entire site is less than 4046.9 m^2. In 2001, immediately the home owner was moved and the town assumed ownership, a treatment system was installed in a 3 m by 6 m treatment shed. Treatment consisted of nine recovery wells with pneumatic top loading pumps, an oil water separator, four 55.4 m activated carbon units, a large bag filter, two air compressors (5 hp and a 7 hp) and air and water manifolds. There were also 35 monitoring and 20 geoprobe wells installed over the years. In May of 2006 a high vacuum system was installed to remove water and vapour from a few of the contaminated wells. This system operated during the warmer months over two years. The water treatment system also continued to operate during this time. As of 2008, over 3182.3 L of kerosene was recovered from the bedrock. Over a million gallons of water was treated by the water treatment system. No remediation work has occurred since 2009. The site is planned for closure in 2012 or 2013. The most likely source was the former home owner's above ground storage tank and/or the buried fuel supply line. They were on assistance and no one paid much attention to usage. Data were collected from this well from April 13 to April 18, 2012. Also investigated during the same monitoring period in this site is another well called recovery well nine (RW-9). This well is approximately 6 m from the Faulkner well. The well is 10 cm diameter and opens up into a wider area. The bedrock is highly fractured in this area and drilling through it left an uneven opening in the ground. The well was approximately 11 m in depth but probably less with pieces of rock falling to the bottom of it over the years. After the well was pumped twice, the Gasclam was inserted into the well.

EXPERIMENTAL

The Gasclam was designed to operate remotely; specifically in 50 mm ID monitoring wells. It monitors and records the following: CH_4, CO_2, O_2, CO, H_2S, VOCs, atmospheric pressure, borehole pressure, pressure differential, temperature and water level. It is made from stainless steel and is also intrinsically safe. It is environmentally sealed and has ingress protection rated IP-68. The Gasclam is battery operated and can be powered for up to three months whilst operating on an hourly sampling frequency. Target applications for the Gasclam ground gas monitor include landfill for long term profiling, Brownfield sites for development issues, monitoring for coal mine fires, leakage of crude/petroleum, solvent storage and filling stations, oil refineries for local compliance/regulation, and for below ground carbon capture and storage monitoring regime[1].

The Gasclam has the following technical information: (i) it has a memory which can record and store 65,000 time/date stamped readings, (ii) it weighs 7kg (13.2 lbs), (iii) It has overall length of 85cm (33.5 inches), (iv) the head diameter is 10.8 cm (4.25 inches), (v) its operation temperature range is –5 to +50 °C or 41°F to 122°F, (vi) it is powered by Duracell 1.5v LR20 MN1300 cells or a rechargeable battery pack. Two Gasclam units with PID sensors were modified by incorporating a

[1](www.ionscience.com/products/gasclam)

sorption tube containing Tenax TA (poly-2, 6-diphenyl-p-phenylene oxide) adsorbent (Markes International). This particular sorbent was chosen based on its outstanding selective properties in adsorption and desorption of VOCs over others gases (Kroupa *et al*., 2004). These properties include high thermal stability (Brown, 1996), high hydrophobicity and rapid desorption kinetics (Barro et al., 2009; Lee et al., 2006; Singer et al., 2007; Schripp et al., 2007; Barro et al., 2005; Saba et al., 2001), high breakthrough volume (Baya and Siskos, 1996; Rothweiler and Wager, 1991; Borusiewicz and Zięba-Palus, 2007; Camel and Caude, 1995; Ras and Borrull, 2009; Gallego et al., 2010), inertness towards most pollutants, high mechanical strength, and a good adsorption range of VOCs (Woolfenden, 2010). It has a surface area of 35m^2 per g and a pore volume of 2.4 cm^3 per g (Kroupa et al., 2004). VOCs adsorbed on Tenax TA sorbent tube are analysed by thermal desorption /gas chromatography mass spectroscopy (TD/GC-MS); a method which has already been standardised internationally (ISO 16000-6, 2004).

In-situ VOC sample collection: The two units were installed to monitor continuously on hourly sampling intervals for up to one week. The in-situcontinuous data from the PID was downloaded while the sorbent tubes were removed from the Gasclams and sealed for subsequent TD/GC-MS analysis. The summation of the *in-situ* PID data from the Gasclam shows that the total VOC concentration adsorbed onto the sorbent material during the entire monitoring period are 3785 ppm and 2108 ppm for boreholes 1 and 2 respectively. The sorbent tubes were subsequently analysed ex-situ for VOCs by thermal desorption Gas Chromatography/Mass Spectrometry (TD/GC-MS).

Ex-situ sample analysis: Analyses of the samples were conducted by heating the sorbent tube to 300^oC. The volatile components were then trapped on a cold trap, held at -10$^{\circ}C$, prior to desorption onto the GC column. Desorption of the TD tubes was carried out using a Markes International 50:50 TD system coupled to an Agilent GC/MS. Data acquisition in scanning mode was via a PC running Agilent Chemstation software. The mass of each of the identified VOCs was calculated relative to the standard by assuming that the area of their peaks on the chromatogram is proportional to their masses. The relationship is shown below:

$$A_{is}/Q_{is} = A_x/Q_x$$

Where $A_{is}$is the area of internal standard on the chromatogram, $Q_{is}$is the amount of internal standard = 500ng, A_x is the area of specific VOC on the chromatogram and Q_x is the amount of specific VOC.

RESULTS AND DISCUSSION

Both wells showed variability in VOCs concentration. The concentration of VOCs in well 1 is higher than that of well 2. The value ranges from 20 ppm to 74 ppm for well 1, and 24 ppm to 31 ppm in well 2. Decrease in concentration over time is observed in well 1 whilst in well 2, it is fairly constant during the monitoring period. The average concentration of VOCs in wells 1 and 2 are 31 ppm and 17 ppm respectively. The aggregate concentrations of VOCs over the monitoring period are 3785 ppm and 2108 ppm in boreholes 1 and 2 respectively. This shows that the concentration of VOCs in well 1 is approximately twice that in well 2. The total concentration of adsorbed VOCs in well 1 is 264 mg/m^3 whilst in well 2; it is 242 mg/m^3. Undecane and hexane have the highest and lowest concentrations of 5.64 mg/m^3 (2.14%) and 2.88 x 10^{-3} mg/m^3 (0.0011%) respectively among the identified VOCs in well 1; whilst in well 2, the highest concentration of 7.88 mg/m^3 (3.26%) was recorded for 1,3,5-trimethylbenzene and the lowest concentration of 0.124 mg/m^3 (0.0514%) for 3-tridecene.

Table 1: Volatile Organic Compounds Analytical Results [Sample: MI 148954 (Well 1)]

S.No.	Name of compounds	Individual TIC peak Area	Total mass (mg)	Total concentration (mg/m^3)	% of total area	Cumulative % of total area
1	Undecane	8.96E+08	3.47E-02	5.64E+00	2.14E+00	2.14E+00
2	Decane	7.26E+08	2.81E-02	4.57E+00	1.73E+00	3.88E+00

3	2-Hexyl-1-octanol	6.51E+08	2.52E-02	4.10E+00	1.56E+00	5.43E+00
4	1-(4-bromobutyl)-2-piperidinone	6.03E+08	2.33E-02	3.80E+00	1.44E+00	6.87E+00
5	2,6-Dimethylnonane	4.96E+08	1.92E-02	3.13E+00	1.19E+00	8.06E+00
6	4-Methylnonane	4.72E+08	1.83E-02	2.97E+00	1.13E+00	9.18E+00
7	2-Methyldecane	4.60E+08	1.78E-02	2.89E+00	1.10E+00	1.03E+01
8	2-Cyclohexyldecane	4.51E+08	1.75E-02	2.84E+00	1.08E+00	1.14E+01
9	2,6-Dimethylundecane	4.45E+08	1.72E-02	2.80E+00	1.06E+00	1.24E+01
10	3-Methyldecane	4.05E+08	1.57E-02	2.55E+00	9.67E-01	1.34E+01
11	2,6-Dimethyldecane	3.70E+08	1.43E-02	2.33E+00	8.85E-01	1.43E+01
12	2-Hexyl-1-octanol	3.69E+08	1.43E-02	2.32E+00	8.80E-01	1.52E+01
13	Nonane	3.61E+08	1.40E-02	2.27E+00	8.61E-01	1.60E+01
14	2-Methylundecane	3.52E+08	1.36E-02	2.22E+00	8.40E-01	1.69E+01
15	5-Methyldecane	3.50E+08	1.35E-02	2.20E+00	8.35E-01	1.77E+01
16	1-Methyl-2-propylcyclohexane	3.20E+08	1.24E-02	2.01E+00	7.64E-01	1.85E+01
17	4-Methyldecane	2.86E+08	1.11E-02	1.80E+00	6.84E-01	1.91E+01
18	3-Methylundecane	2.66E+08	1.03E-02	1.67E+00	6.34E-01	1.98E+01
19	2,6,10-Trimethyltetradecane	2.63E+08	1.02E-02	1.66E+00	6.29E-01	2.04E+01
20	4-Methylundecane	2.61E+08	1.01E-02	1.64E+00	6.24E-01	2.10E+01
21	2-Methylnonane	2.56E+08	9.91E-03	1.61E+00	6.11E-01	2.16E+01
22	3-Methyloctane	2.55E+08	9.89E-03	1.61E+00	6.10E-01	2.22E+01
23	3-Methylnonane	2.54E+08	9.85E-03	1.60E+00	6.07E-01	2.29E+01
24	Propylcyclohexane	2.44E+08	9.43E-03	1.53E+00	5.82E-01	2.34E+01
25	Toluene	2.41E+08	9.32E-03	1.52E+00	5.75E-01	2.40E+01
26	2-Hexyl-1-decanol	2.34E+08	9.07E-03	1.48E+00	5.60E-01	2.46E+01
27	2-Methyloctane	2.07E+08	8.02E-03	1.30E+00	4.95E-01	2.51E+01
28	1-Octadecyne	1.97E+08	7.64E-03	1.24E+00	4.71E-01	2.55E+01
29	1-Methyl-2-pentyl cyclohexane	1.93E+08	7.46E-03	1.21E+00	4.60E-01	2.60E+01
30	1-Methyl-2-pentylcyclopentane	1.89E+08	7.30E-03	1.19E+00	4.50E-01	2.64E+01
31	1,2-Dipropylcyclopentane	1.85E+08	7.16E-03	1.16E+00	4.42E-01	2.69E+01
32	4-Methyl octane	1.80E+08	6.98E-03	1.14E+00	4.31E-01	2.73E+01
33	2-Butal-1- octanol	1.74E+08	6.72E-03	1.09E+00	4.15E-01	2.77E+01
34	Octane	1.63E+08	6.33E-03	1.03E+00	3.90E-01	2.81E+01
35	Ethylcyclohexane	1.59E+08	6.17E-03	1.00E+00	3.81E-01	2.85E+01
36	2-Butyl-1,1,3-trimethylcyclohexane	1.45E+08	5.63E-03	9.16E-01	3.47E-01	2.89E+01
37	1-Methyl-2-propylcyclopentane	1.41E+08	5.47E-03	8.89E-01	3.37E-01	2.92E+01
38	cis-1-Ethyl-3-methyl-cyclohexane	1.23E+08	4.75E-03	7.73E-01	2.93E-01	2.95E+01
39	trans-1-Ethyl-4-methylcyclohexane	1.14E+08	4.41E-03	7.17E-01	2.72E-01	2.98E+01
40	2-Methylheptane	1.11E+08	4.28E-03	6.96E-01	2.64E-01	3.00E+01
41	2-Hexyl-1- decanol	1.09E+08	4.21E-03	6.84E-01	2.60E-01	3.03E+01
42	3,5-Dimethylheptane	1.08E+08	4.18E-03	6.79E-01	2.58E-01	3.05E+01
43	Cyclohexanepropanol	1.05E+08	4.07E-03	6.61E-01	2.51E-01	3.08E+01
44	2,6,10-Trimethyldodecane	1.04E+08	4.04E-03	6.58E-01	2.49E-01	3.10E+01
45	Dodecane	1.02E+08	3.94E-03	6.41E-01	2.43E-01	3.13E+01
46	2,6-Dimethylheptane	9.19E+07	3.56E-03	5.79E-01	2.19E-01	3.15E+01
47	p-Xylene	8.14E+07	3.15E-03	5.12E-01	1.94E-01	3.17E+01
48	1,3-Dimethylhexane	8.08E+07	3.13E-03	5.09E-01	1.93E-01	3.19E+01
49	1,6-Dimethyldecahydronaphthalene	7.90E+07	3.06E-03	4.97E-01	1.89E-01	3.21E+01
50	2,6,10-Trimethyldodecane	7.50E+07	2.90E-03	4.72E-01	1.79E-01	3.23E+01
51	2,3-Dimethylheptane	7.29E+07	2.82E-03	4.59E-01	1.74E-01	3.24E+01
52	5-Butyl-4-nonene	5.99E+07	2.32E-03	3.77E-01	1.43E-01	3.26E+01
53	Methylcyclohexane	5.92E+07	2.29E-03	3.72E-01	1.41E-01	3.27E+01
54	trans-1,4-Dimethylcyclopentane	4.86E+07	1.88E-03	3.06E-01	1.16E-01	3.28E+01
55	1,1,2-Trimethylcyclohexane	4.63E+07	1.79E-03	2.91E-01	1.11E-01	3.29E+01

56	1-Methyl-4-iso-propylcyclohexane	4.05E+07	1.57E-03	2.55E-01	9.66E-02	3.30E+01
57	1,2-Dimethylcyclohexane	3.87E+07	1.50E-03	2.44E-01	9.24E-02	3.31E+01
58	trans-1-Ethyl-3-Methylcyclopentane	3.83E+07	1.48E-03	2.41E-01	9.15E-02	3.32E+01
59	Heptane	3.52E+07	1.36E-03	2.22E-01	8.42E-02	3.33E+01
60	2,3-Dimethyldecane	3.51E+07	1.36E-03	2.21E-01	8.39E-02	3.34E+01
61	Methylcyclooctane	2.52E+07	9.76E-04	1.59E-01	6.02E-02	3.34E+01
62	cis-1-Ethyl-3-Methylcyclopentane	2.44E+07	9.44E-04	1.53E-01	5.82E-02	3.35E+01
63	Isobutylmethylketone	2.42E+07	9.35E-04	1.52E-01	5.77E-02	3.36E+01
64	2,4-Dimethylheptane	2.39E+07	9.27E-04	1.51E-01	5.72E-02	3.36E+01
65	cis-1,4-Dimethylhexane	2.17E+07	8.40E-04	1.37E-01	5.18E-02	3.37E+01
66	1,2,3-Trimethylcyclohexane	1.95E+07	7.57E-04	1.23E-01	4.67E-02	3.37E+01
67	1,3-Dimethylcyclopentane	1.88E+07	7.29E-04	1.19E-01	4.50E-02	3.38E+01
68	1,2,4-Trimethylcyclohexane	1.67E+07	6.47E-04	1.05E-01	3.99E-02	3.38E+01
69	2-Methylhexane	1.43E+07	5.54E-04	9.01E-02	3.42E-02	3.38E+01
70	3-Methyl hexane	1.37E+07	5.32E-04	8.65E-02	3.28E-02	3.39E+01
71	trans-1,2-Dimethylcyclopentane	1.25E+07	4.86E-04	7.90E-02	3.00E-02	3.39E+01
72	Cis-1-ethyl-3-methyl cyclohexane	9.62E+06	3.73E-04	6.06E-02	2.30E-02	3.39E+01
73	Ethylcyclopentane	9.03E+06	3.50E-04	5.68E-02	2.16E-02	3.39E+01
74	1,2,3-Trimethyl cyclopentane	8.56E+06	3.32E-04	5.39E-02	2.05E-02	3.40E+01
75	2,3-Dimethylhexane	5.37E+06	2.08E-04	3.38E-02	1.28E-02	3.40E+01
76	1-Methylethyl cyclopentane	4.53E+06	1.75E-04	2.85E-02	1.08E-02	3.40E+01
77	2-Butanone	3.00E+06	1.16E-04	1.89E-02	7.17E-03	3.40E+01
78	3-Methylpentane	2.60E+06	1.00E-04	1.63E-02	6.20E-03	3.40E+01
79	2-Methylpentane	6.80E+05	2.63E-05	4.28E-03	1.62E-03	3.40E+01
80	Hexane	4.58E+05	1.77E-05	2.88E-03	1.09E-03	3.40E+01
81	**Unidentified compounds**	**2.76E+10**	**1.07E+00**	**1.74E+02**	**6.60E+01**	**1.00E+02**

∑ PID VOCs signal (ppm)	∑ PID VOCs (mol)	∑ VOC mass (mg)	Total vol. (m^3)	∑VOCs conc.(mg/m^3)
3785	8.45E-06	1.62E+00	6.15E-03	2.64E+02

Table 2: Volatile Organic Compounds Analytical Results [Sample: MI 148955 (Well 2)]

S.No.	Name of compounds	Individual TIC peak Area	Total mass (mg)	Total concentration (mg/m^3)	% of total area	Cumulative % of total area
1	1,3,5-Trimethylbenzene	9.09E+08	4.77E-02	7.88E+00	3.26E+00	3.26E+00
2	Nonane	6.93E+08	3.63E-02	6.01E+00	2.48E+00	5.74E+00
3	3-Methylheptane	5.73E+08	3.00E-02	4.96E+00	2.05E+00	7.79E+00
4	Undecane	5.46E+08	2.86E-02	4.73E+00	1.96E+00	9.75E+00
5	p-Xylene	5.02E+08	2.63E-02	4.35E+00	1.80E+00	1.15E+01
6	Octane	4.57E+08	2.40E-02	3.96E+00	1.64E+00	1.32E+01
7	2-Methylheptane	4.38E+08	2.30E-02	3.80E+00	1.57E+00	1.48E+01
8	3-Methyloctane	4.14E+08	2.17E-02	3.58E+00	1.48E+00	1.62E+01
9	o-Xylene	4.12E+08	2.16E-02	3.57E+00	1.48E+00	1.77E+01
10	2,6-Dimethyloctane	4.11E+08	2.15E-02	3.56E+00	1.47E+00	1.92E+01
11	Chlorobenzene	3.48E+08	1.82E-02	3.01E+00	1.25E+00	2.04E+01
12	1-Methyl-2-propylcyclohexane	3.36E+08	1.76E-02	2.91E+00	1.20E+00	2.16E+01
13	Phytol	3.31E+08	1.73E-02	2.87E+00	1.18E+00	2.28E+01
14	2,6-Dimethylnonane	3.24E+08	1.70E-02	2.81E+00	1.16E+00	2.40E+01
15	2-Methyldecane	2.98E+08	1.56E-02	2.58E+00	1.07E+00	2.50E+01
16	Heptane	2.92E+08	1.53E-02	2.53E+00	1.04E+00	2.61E+01
17	2-Cyclohexyldecane	2.90E+08	1.52E-02	2.51E+00	1.04E+00	2.71E+01
18	3, 3-Dimethylbutylbenzene	2.85E+08	1.49E-02	2.47E+00	1.02E+00	2.81E+01
19	1-Methyldecahydronaphthalene	2.76E+08	1.45E-02	2.39E+00	9.87E-01	2.91E+01
20	3-Methylnonane	2.75E+08	1.44E-02	2.38E+00	9.83E-01	3.01E+01
21	trans-Decahydronaphthalene	2.57E+08	1.35E-02	2.23E+00	9.22E-01	3.10E+01
22	3-Methyldecane	2.52E+08	1.32E-02	2.19E+00	9.03E-01	3.19E+01

23	2,5-Dimethylheptane	2.43E+08	1.27E-02	2.11E+00	8.70E-01	3.28E+01
24	4-Ethyloctane	2.36E+08	1.24E-02	2.05E+00	8.46E-01	3.37E+01
25	4-Methylnonane	2.32E+08	1.22E-02	2.01E+00	8.31E-01	3.45E+01
26	Propylbenzene	2.21E+08	1.16E-02	1.91E+00	7.90E-01	3.53E+01
27	Ethylcyclohexane	1.97E+08	1.03E-02	1.71E+00	7.07E-01	3.60E+01
28	Propylcyclohexane	1.93E+08	1.01E-02	1.67E+00	6.90E-01	3.67E+01
29	2,3-Dimethyloctane	1.86E+08	9.75E-03	1.61E+00	6.66E-01	3.73E+01
30	2,6-Dimethylheptane	1.74E+08	9.12E-03	1.51E+00	6.23E-01	3.80E+01
31	2-Methyl-1-decanol	1.72E+08	9.02E-03	1.49E+00	6.16E-01	3.86E+01
32	1-Ethyl-2-methylbenzene	1.66E+08	8.69E-03	1.44E+00	5.94E-01	3.92E+01
33	1-Ethyl-3-methylbenzene	1.63E+08	8.53E-03	1.41E+00	5.83E-01	3.98E+01
34	Methylcyclohexane	1.57E+08	8.25E-03	1.36E+00	5.64E-01	4.03E+01
35	1-Methyl-2-propylcyclopentane	1.54E+08	8.05E-03	1.33E+00	5.50E-01	4.09E+01
36	1,2-Dipropylcyclopentane	1.45E+08	7.63E-03	1.26E+00	5.21E-01	4.14E+01
37	3,5-Dimethyloctane	1.36E+08	7.12E-03	1.18E+00	4.87E-01	4.19E+01
38	3-Ethyl-2-methylheptane	1.35E+08	7.08E-03	1.17E+00	4.84E-01	4.24E+01
39	4-Methyldecane	1.32E+08	6.92E-03	1.14E+00	4.73E-01	4.28E+01
40	Isopropylbenzene	1.25E+08	6.58E-03	1.09E+00	4.49E-01	4.33E+01
41	Cyclohexanepropanol	1.21E+08	6.35E-03	1.05E+00	4.34E-01	4.37E+01
42	1-Ethyl-3-methylcyclohexane	1.11E+08	5.82E-03	9.63E-01	3.98E-01	4.41E+01
43	Cis-1,3-Dimethylcyclohexane	1.08E+08	5.67E-03	9.37E-01	3.87E-01	4.45E+01
44	1-Methyl-2-pentylcyclohexane	1.07E+08	5.58E-03	9.23E-01	3.82E-01	4.49E+01
45	5-Methyldecane	1.03E+08	5.38E-03	8.89E-01	3.67E-01	4.53E+01
46	1-Ethyl-4-methylcyclopentane	1.00E+08	5.26E-03	8.70E-01	3.59E-01	4.56E+01
47	3-Methylhexane	9.52E+07	4.99E-03	8.25E-01	3.41E-01	4.60E+01
48	1-Methyl-4-propylbenzene	8.14E+07	4.27E-03	7.06E-01	2.92E-01	4.62E+01
49	2,6-Dimethyldecane	8.10E+07	4.25E-03	7.02E-01	2.90E-01	4.65E+01
50	1,2-Dibromo-2-methylundecane	7.92E+07	4.15E-03	6.86E-01	2.84E-01	4.68E+01
51	2-Methylhexane	7.82E+07	4.10E-03	6.77E-01	2.80E-01	4.71E+01
52	2,4,6-Trimethylheptane	7.29E+07	3.82E-03	6.32E-01	2.61E-01	4.74E+01
53	1-Tetradecyne	7.08E+07	3.71E-03	6.14E-01	2.54E-01	4.76E+01
54	1,5-Dimethylcyclooctane	6.81E+07	3.57E-03	5.90E-01	2.44E-01	4.79E+01
55	1-Ethyl-2-propylcyclohexane	6.50E+07	3.41E-03	5.63E-01	2.33E-01	4.81E+01
56	trans-1-Methyl-4-isopropylcyclohexane	6.45E+07	3.38E-03	5.59E-01	2.31E-01	4.83E+01
57	2,6,10-Trimethyldodecane	5.73E+07	3.00E-03	4.96E-01	2.05E-01	4.85E+01
58	Cyclododecanemethanol	5.35E+07	2.80E-03	4.63E-01	1.92E-01	4.87E+01
59	1,2,3-Trimethylbenzene	5.12E+07	2.69E-03	4.44E-01	1.83E-01	4.89E+01
60	cis-1-Methyl-4-isopropylcyclohexane	5.12E+07	2.69E-03	4.44E-01	1.83E-01	4.91E+01
61	1,2,3-Trimethylcyclohexane	4.33E+07	2.27E-03	3.75E-01	1.55E-01	4.92E+01
62	1,2-Dimethylcyclooctane	4.27E+07	2.24E-03	3.70E-01	1.53E-01	4.94E+01
63	Isobutyl-3-methylcyclopentane	4.11E+07	2.15E-03	3.56E-01	1.47E-01	4.95E+01
64	Ethylcyclopentane	4.03E+07	2.11E-03	3.49E-01	1.44E-01	4.97E+01
65	Dodecane	3.42E+07	1.80E-03	2.97E-01	1.23E-01	4.98E+01
66	Isobutyl-3-methylcyclopentane	3.18E+07	1.67E-03	2.76E-01	1.14E-01	4.99E+01
67	1,1,2,3-Tetramethylcyclohexane	2.27E+07	1.19E-03	1.97E-01	8.15E-02	5.00E+01
68	Decane	1.95E+07	1.02E-03	1.69E-01	6.97E-02	5.01E+01
69	3-Tridecene	1.44E+07	7.53E-04	1.24E-01	5.14E-02	5.01E+01
70	**Unidentified compounds**	**1.39E+10**	**7.30E-01**	**1.21E+02**	**4.99E+01**	**1.00E+02**

∑ PID VOCs signal (ppm)	∑ VOC mass (mg)	Total vol. (m^3)	∑VOCs conc.(mg/m^3)
2108	1.46E+00	6.05E-03	2.42E+02

Most of the identified VOCs are among USEPA list of 107 compounds whose toxicity and volatility produce a potentially unacceptable inhalation risk to receptors. However, the risk of anyone being exposed to a significant amount of the contaminant is very

low/negligible. This is because; the potential for exposure is during sampling which is a controlled and managed process. Therefore, it cannot be concluded that these wells are potentially dangerous. The result also shows that the total concentration of VOCs (both as measured by Gasclam and as adsorbed by sorbent tubes) from well 1 is higher than that from well 2. Although the two wells contain dangerous VOCs, well 2(see table 2) is actually more dangerous on the basis of the number of thistype of VOCs it is contaminated with. This type of information can be helpful during risk assessment in understanding the regime and distribution of VOCs at different locations on a given site.

CONCLUSION

There is variability in the concentration of VOCs in the two wells. However, whilst well 1 had a higher aggregate VOCs concentration than well 2; the later has more number of dangerous VOCs than the former. This information is very important in risk assessment as it is not just enough to know the quantity of VOCs in a given contaminated site but more important is the knowledge of their types since VOCs can vary not only in concentration but also in behaviour and toxicity. The identified VOCs comprise of those recognised to be significantly hazardous to health and the environment. They include 1, 3, 5-trimethylebenzene, chlorobenzene, propylbenzene, Isopropylbenzene, toluene, p-xylene, and o-xylene. A comparison of the individual concentrations of VOCs in this site with the international standard shows that they have passed the set limits. However, the presence of contaminants does not immediately constitute a risk. There need to be an exposure pathway and a receptor; but at the site, there is neither of these. The use of a PID/Tenax enabled Gasclam enables robust sub-surface VOC gas/vapour monitoring data enabling site zoning and a more effective targeting of remedial efforts on those zones of actual concern leading to savings in both time and money and helping to ensure that the remedial works are more sustainable in line with current guidance. They also save frequent "snapshot" monitoring visits enabling a more accurate representation of sub-surface conditions to be obtained.

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