5 DATA INTERPRETATION

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5.1 General Description of Site Geology

According to the soil classification systems shown on Figure 1.6, soil of particle size finer than 0.075 mm (or 75 μm) is classified as silt and soil of particle size finer than 0.005 mm (or 5 μm) is classified as clay. The results of the particle size analysis indicate that the average percentage of soil samples which are finer than 75 μm at the four testing locations in ascending order is VT4 (5.7%), VT2 (6.4%), VT3 (21.1%) and VT1 (37.1%). By extrapolating the curves of the particle size distribution of all soil samples (Figures 4.1 to 4.13), the clay content of all soil samples appears to be less than 10%.

It should be noted that the range of soil particle size for VT3 is the largest. Coarse sand/gravel fractions make up 14-33% by weight. The results agree in magnitude with the previous data obtained in the TDD/OCTF joint investigation.

5.2 Short-term Soil Vapour Extraction Tests

1. The plots of applied vacuum *vs* flow rate (Figures 4.15 and 4.16) indicate that the soil at VT4 is most permeable, followed by VT2, then VT1, and the soil at VT3 is moderately permeable.

2. *It is documented in the U.S. EPA's Manual of Bioventing*[9] *that it is a standard technique to use vacuum measurement to determine the SVE ROI. With this method, the vacuum (in log-scale) is plotted versus the distance for the SVE well. The ROI is that distance at which the curve intersects a vacuum of 0.1" H_2O (25 Pa) (This value was determined empirically from bioventing initiative sites, as documented in the U.S. EPA's Manual of Bioventing*[9]*).*

3. *Using 0.1" H_2O vacuum as the 'cut-off' level, the SVE ROI for VT1, VT2, and VT4 was estimated to be greater than 12m (the design value); and for VT3, the SVE ROI was estimated to be greater than 10m (Figures 4.17 to 4.20).*

4. *The plots of vacuum vs distance from the SVE well show that the vacuum at the deeper probes is similar to the vacuum at the shallow probes. The short-circuiting scenario through the gravel layer underneath concrete cannot be true if a significant vacuum is still measured at deeper levels. The greater vacuum with depth also indicates flow from the shallow zones to the deeper zones away from the SVE well. This flow pattern will help to aerate the contaminated soils in the vicinity of the water table.*

[9] U.S. EPA (1995) *Manual of Principles and Practices of Bioventing, Volume II: Bioventing Design.* EPA/540/R-95/534a. Office of Research and Development.

5. At VT3, the radial vacuum distribution pattern appears to be uniform, indicating that the likelihood of short channelling is not high *(Figure 4.21)*.

5.3 Long-term Soil Vapour Extraction Tests

VT1

1. In the baseline measurements, the low levels of oxygen and elevated levels of carbon dioxide (2.29% vs. <1% as typically observed under normal soil conditions) and presence of methane suggest that petroleum hydrocarbons may be biodegrading in the subsurface. The introduction of oxygen through SVE/AS will likely enhance accelerate *in situ* biodegradation of hydrocarbons in the soil and groundwater.

2. There were two peaks at the plot of VOC concentration at the blower outlet vs. time, but the final VOC concentration was close to the initial concentration (Figure 4.22), indicating that VOC was being continuously extracted from the SVE well. The fluctuations of the VOC concentration may be attributable to the natural changes in the flow rate and ambient temperature changes. Over a longer-term trend (months), the VOC concentration is expected to drop to a perhaps a half of the initial values according to experience at other sites.

3. The CO_2 concentration was approximately constant throughout the test (Figure 4.22), the CO_2 level indicated that the existence of biological degradation.

4. The gradual increase in O_2 concentration was likely the result of aeration of the unsaturated (vadose) zone. (Figure 4.22).

VT2

5. At VT2, the VOC concentration at the blower outlet increased gradually over time until the middle stage of the test, and increased abruptly near the end of the test (Figure 4.23). This indicated that more and more VOC was extracted from the SVE well.

6. The CO_2 concentration remained very low throughout the test (Figure 4.23), indicating that the extent of biological degradation was limited. This may be because of low contaminant level at VT2.

7. The gradual increase in O_2 concentration was likely the result of aeration of the unsaturated (vadose) zone (Figure 4.23).

VT3

8. The overall VOC concentration at the blower outlet was close to that at VT1 and VT2 (except that there was one distinct peak at VT1) but fluctuated throughout the test

(Figure 4.24), indicating that the amount of extracted VOC was significant but not constant, probably as a response to the flow or temperature fluctuations.

9. Similar to VT2, the CO_2 concentration remained low throughout the test (Figure 4.24), indicating that the extent of biological degradation was limited. This may either be due to lower contaminant level *or flushing out of the CO_2*.

10. The gradually increase in O_2 concentration was likely because of aeration of the unsaturated zone (Figure 4.24).

VT4

11. The VOC concentration increased gradually over time (Figure 4.25), indicating that more and more VOC was extracted from the SVE well.

12. The slightly gradual decrease in CO_2 concentration indicated the soils were well aerated at VT4 and thus CO_2 generated by increased biological activity may have been flushed out (Figure 4.25). This may be a result of the high permeability of this area.

13. The slight gradual increase in O_2 concentration supported this (Figure 4.25).

5.4 Short-term Air Sparging Tests

1. Similar to short-term SVE test, one indication of the ROI (for AS) at VT3 and VT4 can be estimated by plotting the steady state pressure (in log-scale) measured at vapour probes against the distance from AS well (Figures 4.26 and 4.27). This approach is further discussed in Section 5.5.

VT3

2. At a flow rate of 10 cfm (16.8 m^3h^{-1}), the pressure responses at the vapour monitoring probes indicate that the somewhat tight vadose zone does not prevent upward migration of the sparged air (Figure 4.26). It appears that the tighter soils are distributing the sparged air farther from the injection well than at VT4. The soil gas data also provide indication of upward migration.

3. At flow rates of 4 and 2 cfm (6.72 and 3.36 m^3h^{-1}), because of the rapid response in the vadose zone to pressure applied in the saturated zone it appears that there a good connection between the two zones, and that there is not a barrier preventing upward migration of air sparged into the saturated zone. The good pressure distribution in the vadose zone indicates that the sparge well has an effective radius of influence (Figure 4.28).

4. At flow rates of 4 and 2 cfm (6.72 and 3.36 m^3h^{-1}), a comparison with the VT3 SVE test results indicates that it is easier to inject air into the saturated zone than to extract it from the vadose zone.

5. Significant groundwater mounding occurred at the groundwater monitoring wells at VT3, indicating that the soil at the saturated zone is likely less permeable than at VT4 (Figure 4.30).

6. Groundwater mounding occurred at the three groundwater monitoring wells located at 2.5m from the AS well. The range of the mounding varied from about 0.4m at 10 cfm (16.8 m^3h^{-1}) to about 0.05m at 2 cfm (3.36 m^3h^{-1}). The groundwater mounding within the SVE well cannot be measured accurately because of liquid entrainment affecting the performance of the level sensor.

7. Substantial increases in DO at most monitor wells during the relatively short duration of the short term tests indicate good aeration of the groundwater by the AS system and thus a likely AS ROI of greater than 5.5m (the distance to the outer groundwater monitoring well).

8. At a flow rate of 10 cfm (16.8 m^3h^{-1}), the DO increased substantially in 3 wells (W1, W6, and W8) close to the sparge well (Figure 4.32) and thus short circuiting is less likely than if only one well showed an increase. The rapid increase in DO during the VT3 short term AS tests at flow rate of 4 and 2 cfm (6.72 and 3.36 m^3h^{-1}), especially at the wells closest to the sparge well is a good indication of this (Figures 4.32 and 4.33).

9. The higher vadose zone pressures observed during the short-term AS tests indicate that injected air does enter the vadose zone and does not travel horizontally beneath a low permeability upper layer.

<u>VT4</u>

10. The low pressures were likely the result of the very high permeability of the soils at VT4, which did not allow build-up of pressure in the subsurface (Figure 4.27). It should be noted that at VT3, where the soils are less permeable, greater pressures were measured at the vapour probes during the AS testing.

11. The non-uniform pattern of change of water table elevation at groundwater monitoring wells (Figure 4.31) indicates that the soil formation may be so permeable that the sparged air tends to migrate upward from the saturated zone to the unsaturated zone in the immediate vicinity of the AS well.

12. A very small increase in DO was observed (Figures 4.34 and 4.35). This may be a result of the very permeable soils in this area, which did not facilitate good distribution of the injected air. While the VT4 area appears to be amenable to sparging, greater air injection rates may be necessary to distribute aerated

groundwater throughout the treatment area. However, it was quoted in the literature that effective contact with the contaminated soils may not necessarily mean direct contact with an air channel but may be a result of groundwater movement (mixing) associated with IAS, as well as diffusion of oxygen away from the air channels. This may be particularly true if the principal mode of contaminant removal is by biodegradation as will be discussed in Section 6.

5.5 Tracer (Helium) Tests

VT3

1. With AS well air flow rate of 4 cfm (6.72 m^3h^{-1}), the test results indicate influence in one but not all directions radically (Figures 4.36 and 4.37). It appears that most of the helium entered the vadose zone in the vicinity of the 1m probe, and less to the 5m probe along the main direction. The helium concentrations were greater in the shallow probes than in the deep probes. This indicates that the helium may not have emerged from the saturated zone immediately beneath the vapour probes.

2. The results show very good helium readings at 5 m in all 3 radial directions at the 6 cfm (10.08 m^3h^{-1}) injection rate (Figures 4.38 and 4.39). According to the literature[7], in general, the ROI for sites have been determined to be between 10-25 ft (3.05 – 7.63m), based on the API-IAS Database.

   Section 5.4, point 1 states that pressure is "one indication of the ROI (for AS)". The differences in conclusions regarding AS ROI for AS and helium tests are due to the fact that pressure readings in the AS test are not always the best measure of ROI. For this reason, other parameters such as dissolved oxygen, groundwater mounding, and helium were also evaluated. The pressure phenomenon is widely reported in the literature. In the API document[7], it was reported that "due to the propagation of pressure from an air source, the potential for recording a false positive with respect to ROI is possible. That is, a measured change in vacuum pressure at any vadose zone monitoring point may be as a result of the propagation of pressure and not necessarily as a result of a sufficient volume of sparge air emanating from the water table in the vicinity of the monitoring point."

   This is the rationale of the helium test, which provides additional data to estimate the ROI.

3. The helium concentrations in different directions varied (Figures 4.36 to 4.39). However, the current understanding of the movement of air in the saturated zone suggests that radically symmetric air flow is unlikely in IAS system operation. Some non-uniform flows may be expected. In addition, the type of drilling used for the future remediation wells should be properly cased so that high pressure would not fracture the soil and create some preferential channels.

4. As with tracer gases, bubbling is a direct sign of the presence of air channels. However, no bubbling was observed through out the test.

VT4

5. *With AS well flow rate and helium flow rate of 12 cfm (20.16 m^3h^{-1}) and 1 cfm (1.68 m^3h^{-1}) respectively, helium was detected at the 5m deep probes along directions E and F (Figure 4.43).*

6. The responses of the shallow and deep probes installed along the main direction were similar, but that installed along the other two directions were not (Figure 4.40 to 4.43).

5.6 Long-term Combined Soil Vapour Extraction/ Air Sparging Tests

VT3

1. *The significant increases in DO observed during the higher flow short term AS tests did not occur during the combined test when only 2 cfm (3.36 m^3h^{-1}) were injected (Figure 4.46). It should be noted that the AS injection rate was substantially lower than the design value, and this might lead to smaller ROI than full scale system.*

2. The boring log does not indicate a more permeable layer in the saturated zone. This, combined with the test results, do not indicate that air injected in the saturated zone will travel horizontally to outside the zone of influence of the SVE wells.

3. Given that there are SVE wells completely around the perimeter of the full-scale system well field it does not appear that injected air would escape capture.

VT4

4. Mounding of water table at the SVE well and the groundwater monitoring wells did not occur, likely as a result of the very permeable soils in this area (Figure 4.45).

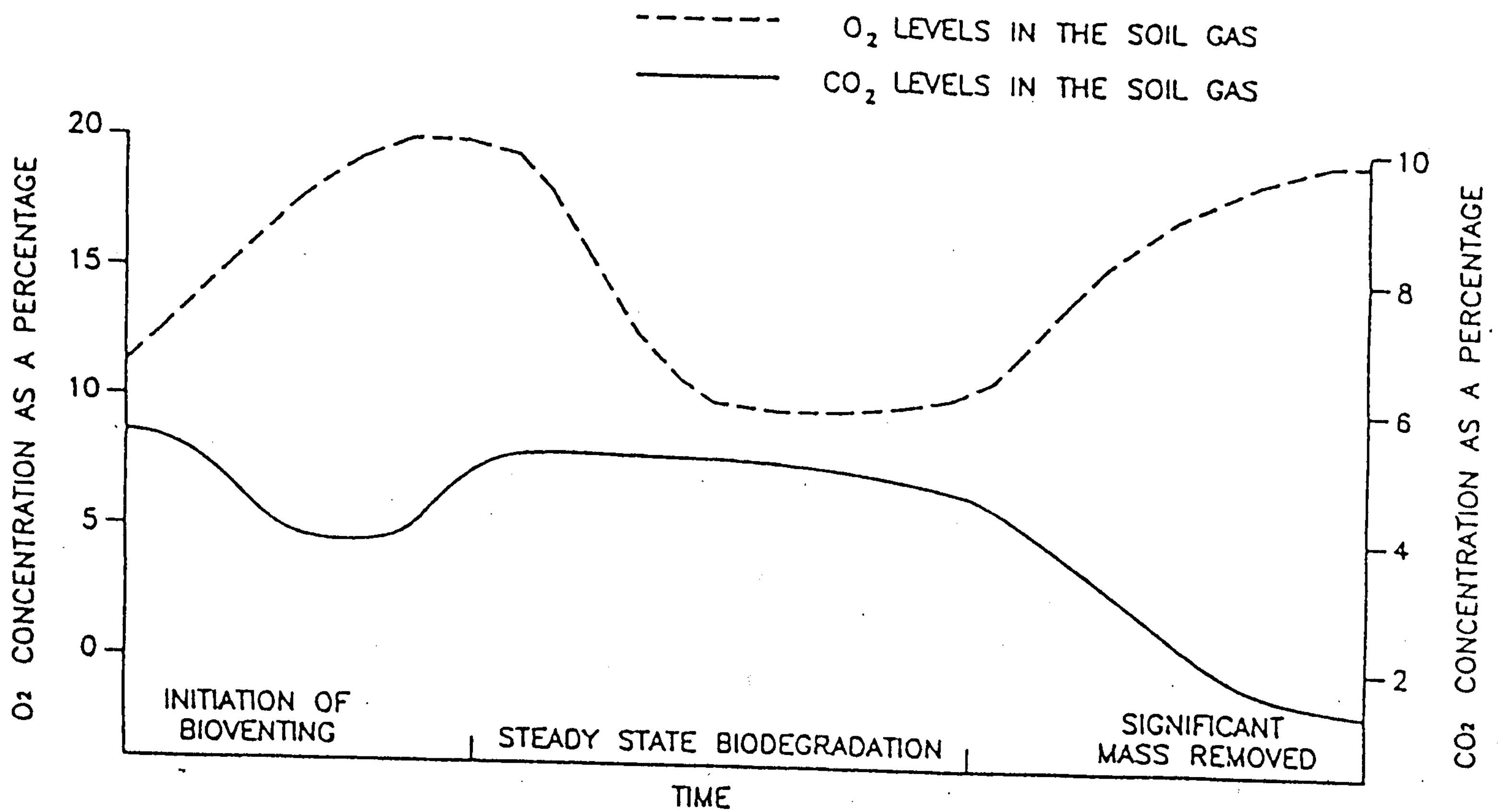
5. The concentration of VOC at the blower outlet fluctuated but increased as a whole, indicating that VOC was continuously extracted (Figure 4.49). The relatively high CO_2 concentration indicated that aerobic biological action was occurring (Figure 4.49). Because of the permeable soils on the vicinity of VT4, the injected air did not appear to distribute substantially away from the AS well. A higher air injection rate would likely be necessary to substantially increase the DO within 5m of the injection well. The trends of CO_2 and CH_4 concentration at the vapour probes were same as that at the blower outlet. The typical trends of CO_2 and O_2 concentration during bioventing are shown on Figure 5.1.

In practice, air sparging and soil vapour extraction treatment for contaminated sites are conducted for over 18 months (refer to Appendix M). Therefore, the actual trend of change in gases probably could not be monitored in our pilot tests, which were conducted for relatively short period.

5.7 Computer Modelling on Permeability of Soil

The results of the computer modelling (Table 4.1) indicate that the permeability of soils at VT3 is the lowest. The calculated permeability values indicate that the soils underlying VT2 and VT4 are close to sandy gravel; the soils underlying VT1 are close to sand; and the soils underlying VT3 are close to silty sand to sandy gravel.

The results of the permeability test roughly agree with the % silt content, except the soils at VT1 have higher % silt than that at VT3 (Figures 4.1, 4.2 and 4.5 to 4.8). As mentioned in Section 3.2, this sieve analysis may not be absolutely representative of the field permeability because the soil samples were taken from cuttings for an air rotary drill rig. However, the sieve analysis can be used as an indicative figure for initially setting the pressure across the SVE/AS system during commissioning.



Source: Suthersan, S. S. (1996) *Remediation Engineering: Design Concept*, p 362. CRC-Lewis, Boca Raton Fla.

Maunsell	TITLE **Typical O_2 and CO_2 Percentage in Soil Gas during Bioventing**	MAUNSELL ENVIRONMENTAL MANAGEMENT CONSULTANTS LTD			
		PROJECT NO	C418	FIGURE NO.	Figure 1.1
		DESIGNED/ CHECKED		DATE	Dec 1998