6 EVALUATION OF RESULTS AGAINST CRITERIA IN EIA REPORT

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6 EVALUATION OF RESULTS AGAINST CRITERIA IN EIA REPORT

As spelled out in the EIA report, the pilot test aims to evaluate the feasibility of SVE/AS as a remedial technology for the clean-up of subsurface contamination at KTA apron. Further, the results of pilot test will form a design basis for the system optimisation. The pilot test feasibility was evaluated against five criteria, namely the radius of influence, remediation period, free product migration, preferential pathway and biological action. The EIA report has suggested the corresponding criteria that are discussed in the following sections.

6.1 Radius of Influence (ROI)

In long-term SVE test, as the test progresses, there may be a slight change of soil permeability (as soil matrix is disturbed by the air flow) resulting in vacuum changes. In some cases, there may be a drop of static vacuum at the distant monitoring locations. The soil can dry out as a result of venting. This will increase the effective porosity and thereby reduce the resistance to flow and hence the vacuum. There may also have been some measurement error if the readings were at the very low end of the gauge scales. Change in barometric pressure can also impact pressure measurements using differential pressure gauges. Therefore, the long-term test should not be designed to measure the ROI, but an evaluation of the change of gas concentration.

In combined SVE/AS test, contrary to the individual AS test conducted earlier, vacuum (negative) responses were recorded at the probes as opposed to positive pressure readings. Additionally, the vacuum readings were correspondingly lower than those recorded during the individual SVE test. This observation provides evidence that the mechanisms of SVE and AS are acting together in creating effective SVE/AS system.

It should be noted that the vacuum measurements by itself are not good indication of the ROI during the combined test case, as the vacuum from SVE and positive pressure from AS may cancel out each other especially at locations closer to the AS wells. Detection of very low vacuum does not imply low flow, as flow is due to pressure gradient rather than static pressure. Flow measurement may be useful to verify the ROI but was difficult to conduct due to the low magnitude of flow. As a result, the ROI for SVE and AS should be established individually rather than in the combined test.

6.1.1 ROI for SVE

SVE radius of influence (ROI) as defined elsewhere in the text is the distance at which the subsurface vacuum is 0.1" H_2O column (25 Pa). In application, the number of extraction wells required is based on the ROI of individual wells. The SVE wells are placed such that ROIs overlap and thus treat the entire contaminated area to maximise the recovery of contaminants and to expedite the clean up time.

The ROI for VT1 to VT4 were also calculated based on Pore Volume Exchange (PVE) and Pore Gas Velocity (PGV). This is the standard industry approach, as documented in U.S.

Army Corps of Engineers' Manual entitled "Engineering and Design - Soil Vapour Extraction and Bioventing" (1995) (Appendix N). This method is applicable because there is an effective surface seal. The calculation is also site specific as the air-filled porosity (0.3) is measured from the Phase II soil samples[2]. The ROI was calculated to be approximately 12m at a flow rate of 20 cfm (3 pore volumes/ day). Therefore, at 20 cfm, there would be approximately 1095 pore volume exchanges per year (3 per day) in 2.2m treatment zone that is 12m in diameter. The details of the calculation are also provided in Appendix N.

Another standard method based on oxygen utilisation was also used to calculate the ROI for VT4 (higher contamination area). This method is documented in the U.S. EPA Manual entitled "Bioventing Principles and Practice, Volume II – Bioventing Design" (1995) (Appendix O). This method is applicable to VT4 (high permeability) because it is stated in the Manual that "in a high permeability soil, air flow rates sufficient to supply oxygen may occur at pressure differentials that cannot be measured. In the author's experience, if a pressure criterion of 0.1" H2O (25 Pa) is used, the estimated ROI will be conservative for well spacing and site aeration". By using this method, the resulting ROI for VT4 is 22m. The details of the calculation are also provided in Appendix O.

A summary of the ROIs for AVE is drawn up in Table 6.1.

Table 6.1 Summary of ROIs for SVE

Test Location	Short-term SVE (based on vacuum measurement)	Short-term SVE (based on PVE technique)	Long-term Combined SVE/AS (based on O_2 utilisation)
VT1	> 20 m	~ 12 m[a]	Not applicable
VT2	> 20 m	~ 12 m[a]	Not applicable
VT3	> 10 m	~ 12 m[a]	Not applicable
VT4	> 20 m	~ 12 m[a]	22 m

a   *This is the ROI if operate at flow rate of 20 cfm.*

6.1.2 ROI for AS

During the helium tests, at both VT3 and VT4, helium concentration was clearly measured at 3 direction at the 5m probes. (refer to Figures 4.38 and 4.43). This provides one indication of ROI.

DO is a conservative estimate of ROI (as biodegradation consumes DO and therefore DO is often an underestimate of ROI). Our data show that at VT3 and VT4, substantial increase in DO occurred at 2.5m, and at 5.5m at some cases.

A summary of the ROIs for AS (for VT3 and VT4) is drawn up in Table 6.2.

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Table 6.2   Summary of ROIs for AS

| Test Location | Short-term AS | | |
	Helium Test	DO Concentration	Water Table Mounding
VT3	About 5 m	About 5m	About 5m
VT4	About 5 m	4 to 5.5m[a]	Not determined

a   If VT4 is operated at the design AS flow rate, it is expected that the ROI would be at ≥ 5m.

6.2   Clean Up Time Based on Volatilisation

VOC removal rates determined in the pilot test will be used to evaluate the time required for cleaning up the site to an agreeable standard. It should be noted that two mechanisms are involved in SVE/AS method, namely enhanced biodegradation and air stripping. While aspect of enhanced biodegradation will be addressed in forthcoming section, air stripping in terms of VOC removal rate is discussed as follows.

6.2.1   Clean Up Time Based on Site Data

Attempt was made to calculate the clean up time based on volatilisation using site data and test results of long-term SVE/AS combined tests conducted at both VT3 and VT4. However, it should be noted that as the contamination level at VT3 was assumed to be the depth-averaged soil analysis results of the adjacent monitoring wells MW249, MW250, MW251 & MW259 (as documented in Technical Report No. RA24[2]), was below the clean-up target (1000 mg/kg TPH). Therefore only VT4 was assessed for clean up time.

For VT4, the contamination level was assumed to be the depth-averaged results of the soil samples taken at adjacent monitoring wells MW261 and MW269. The relevant, processed data for VT4 are given in Table 6.2. The anticipated steady stripping rate for VOC with pilot test flow is 1.8×10^{-2} kg/cfm/hr. Taking a conservative estimate that the steady removal rate shall be 50% of the initial rates, the stripping rate at pilot test flow (i.e. 52.4 cfm) will be 0.943 kg/hr. On the other hand, the mass of contaminant to be air-stripped is calculated to be 2,808 kg. Hence, the time required to clean up the area in vicinity of VT4 by air stripping is worked out as 4.1 months.

It should be acknowledged that the favourable situation at VT4 may not necessarily be indicative of the whole Hot Spot B. Therefore, calculations using the worst-case soil at Hot Spot B and typical clean up rates are presented in the next section.

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Table 6.3   ***Calculation Table for Contaminant Removal by SVE/AS at VT4***
(Worst-case estimates assuming no removal by biodegradation)

	VT4
	VOC reading Adjusted
PILOT TEST	
[a]*Pilot Test SVE flow (cfm ; m^3h^{-1})*	52.4 ; 89.0
Total Test Hour (Hour)	112
[b]*Volume of Soil Air Extracted (m^3)*	9968
[c]*VOC conc. In Extraction Stream (ppmv)*	4460[d]
Total Volume of VOC Extracted (m^3)	44.5
[e]*Equi. Mass of Contaminant Stripped by SVS/AS (kg)*	215
Pilot Test Stripping Rate (kg/cfm/hr)	3.63×10^{-2}
[f]*Contamination Level (mg/kg)*	1776
[g]*Contamination to be Removed (mg/kg)*	776
ROI (m)	12
[h]*Depth of Contaminated Soil (m)*	4.0
[i]*Density of Soil (kg/m^3)*	2000
[j]*Mass of Contaminated Soil (kg)*	3.619×10^6
[k]*Mass of Contaminant to be Removed (kg)*	2808
[l]*Anticipated Steady Stripping Rate (kg/cfm/hr)*	1.8×10^{-2}
[m]*Stripping Rate at pilot test flow, i.e. 52.4 cfm (kg/hr)*	0.943
[n]*Time for Clean-up (hr)*	2978
Time for Clean-up (month)	4.1

Notes:

A – *Mean SVE flow rate over the total test hour*

b - *(Mean SVE flow x Total test hour)*

c – *Geometric mean of PID readings the total test hour*

d – *10 times to the PID readings adjusted for quenching of methane.*

E – *Volume to mass conversion based on R.T.P. (i.e. molar volume of $0.024m^3$) and a M.W. of 116g.*

F – *Average TPH content in soil samples of boreholes ID.261 and 269 in proximity of VT4, as documented in Technical Report No. RA24 Kai Tak Airport Contamination Assessment Phase 2 Final Report (MCAL in association with CES, January 1998)*

g - *(Contamination level - the target level i.e. 1000ppm TPH)*

h – *Soil depth from 2m to 6m below grade*

I – *Assumed*

J - *[(ROI)^2 x π x Soil Depth x Soil Density]*

K - *(Mass of contaminated soil x contamination to be removed)*

L - *50% of pilot test stripping rate*

m - *(Anticipated steady stripping rate x 52.4 cfm)*

n - *(Mass of contaminant to be removed / Stripping rate at pilot test flow)*

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6.2.2 Clean Up Time Based on Typical Literature Values

Based on the results reported in Technical Report No. RA24[2], six most contaminated locations (MW241, MW242, MW250, MW253, MW259, and MW262) within Hot Spot B were selected for this calculation. The spatial distribution of TPH at each location is tabulated in Table 6.4.

Table 6.4   Vertical Distribution of TPH at Six Most Contaminated Locations within Hot Spot B

	MW 241	MW 242	MW 250	MW 253	MW 259	MW 261
TPH at 2-3m below grade (mg/kg)	338	5360	2675	20	52	4440
TPH at 3m or more below grade (mg/kg)	2522	29	133	4061	21728	No data
Averaged TPH concentration = 3760 mg/kg						

As reported in the standard "CRC Handbook of Physical Properties of Organic Chemicals", the averaged vapour pressure of isomers of C10 and C11 are 2.1mm Hg and 0.52 mm Hg respectively, these meet the criteria of chemicals amenable to SVE (0.5 mm Hg). On the other hand, the laboratory quantification of the proportion of C6-C11 fraction (volatile fraction) within the whole C6-C36 fraction of the six most contaminated samples collected within Hot Spot B is tabulated in Table 6.5.

Table 6.5   Quantification of Proportion of C6-C11 Fraction

Sample ID	C6-C11 (mg/kg)	C6-C36 (mg/kg)	(C6-C11) / (C6-C36) x 100%
MW241-2	954	2522	38 %
MW242-1	2880	5360	54 %
MW250-1	1013	2675	38 %
MW253-2	2543	4068	63 %
MW259-2	7349	21728	34 %
MW261-1	1741	4440	39 %
		Mean =	44 %

Therefore, the percentage of volatile fraction of the THP contaminant is 44%. That means 44% of the TPH would be removed by means of volatilisation and the remaining 56% would be removed by means of biodegradation.

The following assumptions were made for this calculation:

1)   Thickness of the contaminated zone is 2m (from 2 to 4m below grade)

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2)   *25% of the contaminated soil is located at the vadose zone (with reference to boring log contained in Technical Report No. RA24²)*

3)   *Bulk density of soil is 1765 kgm³*

The details of the calculation are provided in Appendix P. The clean up time attributed to volatilisation for the whole area enclosed by the six locations (approximately 59500 m2) with respect to VT1 to VT4 are tabulated in Table 6.6.

Table 6.6   Clean Up Time for Volatile Fraction at VT1 to VT4

| Test Location	Extraction Time (months)
VT1	11.7
VT2	14.7
VT3	10.3
VT4	4

6.3   Clean Up Time Based on Biodegradation

6.3.1   Clean Up Time Based on Site Data

In situ biological degradation was evidenced by the increasing level of carbon dioxide in the soil gas extract as a result of microbial respiration[10]. *It is noted however that the carbon dioxide level at VT4 showed an increasing trend.*

The following give an estimate of the biodegradation of contaminant by measuring the metabolic by-product (carbon dioxide) using the method employed in other airports (New York JFK airport, Appendix L). For KTA site, the hydrocarbon degrading bacteria was found to be present in the *Technical Report No. RA24²*.

The carbon dioxide level in vapour samples at SVE blower outlet was used to estimate the mass of hydrocarbons aerobically degraded in the vadose and saturation zone (refer to Appendix L). The geometric mean of CO_2 level in the sample was firstly normalised by subtracting the background level resulted from the *in situ* anaerobic degradation. The background level was assumed to be measured at the first trace of soil gas leaving the blower outlet (i.e. t = 0). Taking account of the test time, the volume of biological CO_2 was converted to mass. The mass of hydrocarbons biologically oxidised is evaluated using the following equation with reference to hexane:

$$C_6H_{14} + 9.5O_2 \rightarrow 6CO_2 + 7H_2O$$

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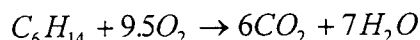
[10]   Wong, J. H. C., Lim, C. H. and Nolen, G. L. (1997) *Design of Remediation System*, p 263. CRC-Lewis Press, New York.

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Based on the molar ratio, approximately 1 kg of hydrocarbons is oxidised for every 3 kg of carbon dioxide generated. Additionally, 50% yield factor was assumed for partial CO_2 utilisation by microbial synthesis of cellular mass. The calculation of the mass of hydrocarbon biologically oxidised during the SVE/AS combined test at VT4 is illustrated in Table 6.7.

Table 6.7   Calculation Table for Contaminant Removal by Biodegradation at VT4
(Worst-case estimates assuming no removal by Volatilisation)

		VT4
Carbon Dioxide Level (%)	Background (T=0)	8.2
	Geometric mean (for 112 hrs)	9.7
	Difference (normalised level)	1.5
Total Test Hour (hour)		112
Pilot Test SVE flow (cfm ; m³/hr)		52.4 ; 89.0
Total Volume of Soil Air Extracted (m³)		9968
ᵃVolume of Biological CO_2 generated (m³)		150
ᵇMass of Biological CO_2 generated (kg)		275
ᶜMass of Contaminant Biologically Oxidised (kg)		45.7
ᵈBiodegradation Rate (kg/hr)		0.41
Mass of Contaminant to be Removed (kg)		2808
ᵉTime for Clean-up (hr)		6849
Time for Clean-up (month)		9.4

Notes :
a - *(Total volume of soil air extracted x normalised CO_2 level)*
b - *Volume to mass conversion based on R.T.P. (i.e. molar volume of $0.024m^3$) and a M.W. of 44g.*
c - *Based on that 1kg of hydrocarbons is oxidised for every 3 kg of CO_2 generated and a 50% yield factor was assumed.*
d - *(Mass of contaminant biologically oxidised / total test hour)*
e - *(Mass of Contaminant to be Removed / Anticipated Biodegradation Rate)*

6.3.2   Clean Up Time Based on Typical Literature Values

This cleaning up time for biodegradation within Hot Spot B (including vadose zone and saturated zone) was calculated using the same set of data and assumptions presented in Section 6.2.2. The additional assumptions for this calculation are:

1)   Biodegradation rate is 10 mg/kg/day at vadose zone and 1-2 mg/kg/day for AS
2)   Level of clean up target is 1000 mg/kg

The details of the calculation are given in Appendix Q. and the main results are given in Table 6.8

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Table 6.8   *Cleaning Up Time Based on Biodegradation Within Hot Spot B*

Zone	Cleaning Up Time Based on Biodegradation
Vadose Zone	*3.7 months*
Saturated Zone	*1.5 to 3 years*

6.4   Groundwater Extraction by SVE

Although not an objective of the SVE system, it was noted that in the pilot test at VT3 and VT4, an average of 3.5 litres of groundwater was collected in the water separator for 1-day operation. Projecting this rate to the full-scale system consisting of 350 SVE wells, 1,225 litres of groundwater will be collected each day and disposed of. Even with large safety factor built in, this small quantity of groundwater could be easily addressed by the present oil interceptor with adequate capacity.

6.5   Implication on VOC Emission Treatment

The emission that results from the extraction of soil gas should be adequately controlled or treated to an acceptable level before it is being discharged.

Based on the pilot test measurements, a maximum of 1,000 ppm VOC in the untreated SVE discharge was recorded. Applying this worst case scenario in the full-scale system, no more than 50 ppm of VOC will be discharged into atmosphere, given that the catalytic oxidiser as for VOC treatment in the full-scale system has a removal efficiency of 95%. Therefore the impact due to VOC emissions from the SVE/AS operation would be minimal *(Refer to Appendix R for the details of the calculation)*.

6.6   Lateral Migration of Free Product

Sparged air introduced into the saturated zone may disperse free product. The dispersion is undesirable if it drives contaminants out of the decontamination site bringing about a secondary pollution. As such, AS is usually deployed in association with SVE to control the off-site contaminant migration.

1)   To evaluate possible free product migration, the thickness of contaminant (free product) in monitoring wells was monitored before and after the pilot test. Neither wells in VT3 nor VT4 showed to have a measurable free product layer, although at VT3 and VT4 free product was observed in collected water in the knockout drum.

2)   The test wells were located in some of the more highly contaminated areas of the site and the lack of free product migration should be noted.

3)   The full-scale system will have SVE wells outside the area of free product, thereby providing capture in the unlikely event that free product does migrate.

4)   For the full-scale system, the air intake wells will be used to monitor the presence and movement, if any, of free product. Where substantial accumulations of free product are observed in the air intake wells it may removed via bailing.

6.7   Preferential Pathways

Preferential pathways at the SVE/AS site are undesirable since they would compromise the efficiency of subsurface aeration and extraction of VOCs. The existence of preferential pathways should therefore be taken into account in designing full-scale SVE/AS system.

There were variations of differential pressure at radial monitoring probes at VT3 and VT4 during the short term and long term SVE tests. It suggests the likely existence of preferential pathways in the vadose zones of VT3 and VT4.

Significant variations in differential pressure at radial monitoring probes were observed at VT4 but not at VT3 during the AS tests. These suggest that preferential pathways may exist in the saturated zone of VT4.

Under similar interpretation, the significant variations of differential pressure at radial monitoring probes during SVE/AS combined test at VT3 & VT4 suggest that vadose zones of both VT3 and VT4 may contain preferential pathways.

Although preferential pathways were observed the relatively large cluster of wells with overlapping ROIs will help to fully aerate the soils requiring treatment.