PART IIB 2010

DR A AL-TABBAA

4D14 Contaminated Land & Waste Containment
2010

Q1. a) Organic matter in the waste is initially degraded under aerobic conditions. The products of these reactions may include nitrates, sulphates, CO_2 and water – generally stable compounds.

Once the free air is exhausted reactions will take place under anaerobic conditions. These reactions convert unstable matter into gases such as methane, ammonia, CO_2, H_2S. Other products like alcohol's and carboxylic acids may also be produced.

[20%]

b) Clay particles have plate-like structure with water present between them. The clay particles are –vely charged and attract cations. (+ve). The charged surface and the adjacient distributed charge together are called double layer – which can hold water tightly. This space is therefore not available for pore water migration. However, the diffused double layer's thickness can change in the presence of certain chemicals/contaminants. This can have an adverse effect on the hydraulic conductivity.

Factors effecting thickness of diffused double layer are Dielectric constant of medium, Boltzman constant, temperature, electrolyte concentration, cation valency.

[20%]

1c)

Year	Rate	Population	Waste	Waste arisings (tons)	Cum Total
2010	5%	39900	30 kg	62244	—
2011	5%	41895	30 kg	65356.2	127600.2
2012	5%	43990	30 kg	68624.4	196224.6
2013	3%	45310	20 kg	47122.4	243347
2014	3%	46669	20 kg	48535.8	291882 t

Land(fill) cell dimensions = 125 × 175 × 15 m

= 328125 m^3.

Unit weight = 8 kN/m^3.

∴ Land fill capacity = 8 × 328125 kN

= 2625000 kN.

= 262500 tons.

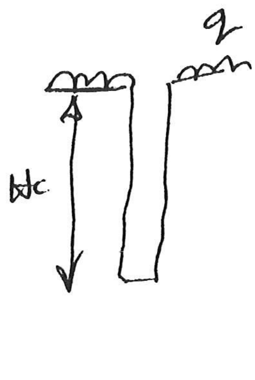
∴ This capacity should suffice until middle of 2014 (but not until end of 2014) ≃ 4.5 years

[30%]

1d) i) C_u = 40 kPa.

γ_{sat} = 18.5 kN/m^3.

q = 20 kpa



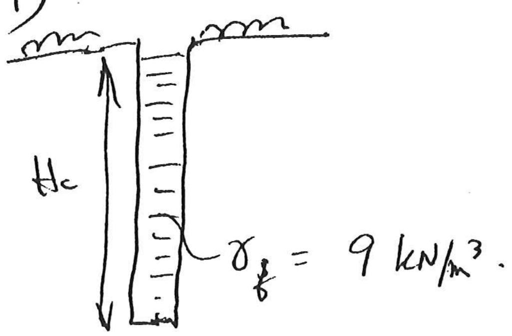
$$H_c = \frac{4c_u - 2q}{\gamma}$$

$$= \frac{4 \times 40 - 2 \times 20}{18.5}$$

$$= 6.486 \simeq 6.5 \text{ m}$$

[15%]

ii)



$$H_c = \frac{4c_u - 2q}{\gamma - \gamma_f}.$$

$$= \frac{4 \times 40 - 2 \times 30}{(18.5 - 9)}$$

$$H_c = 10.526$$

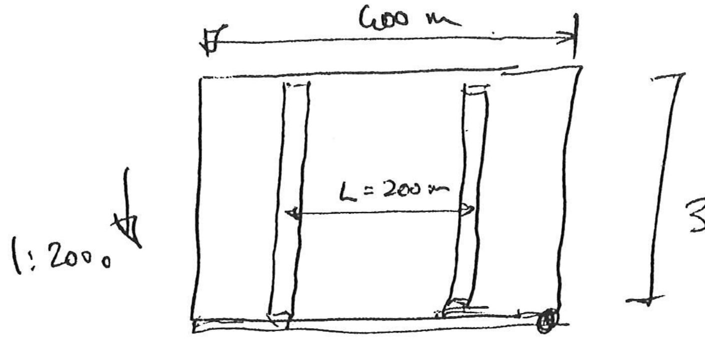
$$\simeq 10.5 \text{ m}$$

[15%]

Assessor's comment:

The first two parts tested the candidates on their understanding of the biological reactions that take place in landfill and the resultant products and the importance of the thickness of diffused double layer on the hydraulic conductivity of the clay liners. The third part was on the estimation of waste arisings allowing for annual changes in population and changes in waste generation due to recycling over years. This year the question asked the candidates the duration of service from a landfill cell. Most students did this part well but a few candidates could not deal with the open ended time duration. The final parts of this question were on the stability of a trench with and without slurry backfill. Most students got these parts right although a few made numerical errors. Surprising there were a few who tried to derive the height of unsupported cut that can be made in clay, but got confused half way through this.

Q 2) a)



Plan view

$h_{max} = 1.5 - 0.1$
$= 1.4$ m

using data sheets

$$L = 2 h_{max} \sqrt{\frac{K}{q}}$$

$$200 = 2 \times 1.4 \times \sqrt{\frac{2.5 \times 10^{-3}}{q}}$$

$q \Rightarrow 4.9 \times 10^{-7}$ m²/s flowing into drainage layer.

$\therefore Q = q \times 400 = 4.9 \times 400 \times 10^{-7} = 1.96 \times 10^{-4}$ m³/s

$\therefore$ for a year volume $Q = 1.96 \times 10^{-4} \times 365 \times 24 \times 3600$ m³.

$= 6181.056$ m³.

This is 10% of rainfall volume.

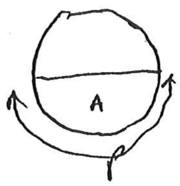
$\therefore$ Rainfall volume $= 61810.56$ m³.

$\therefore$ Rainfall $= 0.515$ m/year.

$$V = \frac{1.486}{n} R_h^{2/3} S^{1/2}$$

Pipe half-full

~~Vo~~



$$R_h = \frac{A}{P} = \frac{\pi r^2/2}{\pi r} = r/2$$

$$R_h = \frac{0.56}{4} = \frac{0.28}{2} = 0.14$$

$S = 1/2000$

$n = 0.009.$

$$\therefore V = \frac{1.486}{0.009} \times (0.14)^{2/3} (1/2000)^{1/2}$$

$v =$ ~~1[illegible]~~ 0.995 m/s. ~~(a little bit high → [illegible])~~ ~~but ok.~~

≃ 1m OK

[50%

~~2~~2(b)

2b) The zones of rapidly changing temperature or density are called thermoclines or pycnoclines.

Ocean environment can be divided with depth into three zones namely
a) permanent pycnocline - shallow depth where changes in temperature take place continuously
b) intermediate waters and
c) deep waters

Dissolved oxygen content also reduces from shallow waters to deep waters.
This will effect the end products formed from the waste disposed.
Between 150m to 1000m relatively, low dissolved oxygen exists. This level is refereed to as 'oxygen minimum zone'.

Two important considerations regarding considering the ocean as a waste repository are
- permanent pycnocline and
- oxygen minimum zone

Similarly, the waste distribution is influenced by ocean topographical features such as

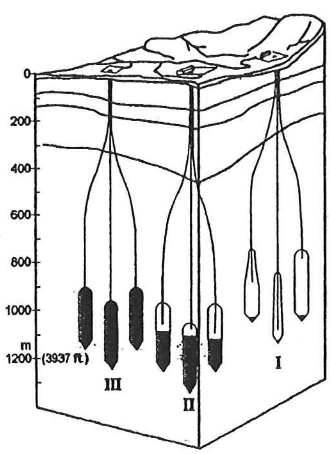
- continental shelf → limited distribution
- continental slope → Extensive spreading.
- abyssal plains → No distribution
- abyssal hills → Large, extensive distribution - Ecology damage possible. [20%]

[30%]

Q 2 c)

Brine-balanced technique involves floating the liquid waste (lighter than brine). The cavern is always full of liquid. When more waste is added the excess brine is displaced via pipes in casing to a brine holding pond. If waste is removed, the reverse happens.

The above technique can also be used if the waste has higher density than brine. The inlet point for waste and outlet point for brine are interchanged.



Various stages of solution mines usage to store liquid waste are shown in the figure

[20%]

Assessor's comment Q2:

The first part of the question was on LCRS analysis and the candidates were asked to estimate the maximum rainfall that the LCRS can cope with at a site and then to check that the system can cope with the leachate flow arriving at the base of the landfill. Almost all candidates who attempted this question could set up the solution well. A few produced near perfect solutions, while most candidates got one half or the other correct, but made numerical errors in working the other half. The second part of the question was on Ocean Environment for waste disposal. Most candidates had good idea on the effect of temperature and topography on the spread of waste. The final part of the question was on solution-mined caverns. Again most candidates produced satisfactory answers although different level of detail was included.

3 (a) Contaminant properties that affect the choice of remediation techniques:
Density
Vapour pressure or boiling point
Solubility
Adsorption coefficient (Sometimes called distribution coefficient or partition coefficient)
Henry's Constant (a combination of vapour pressure and solubility) It is the ratio of the amount in the air to that in the water.
Viscosity

The majority of petroleum hydrocarbons have low density, less than 1, i.e. float on water, (called LNAPLs) so do not penetrate deep below the water table. Generally they are have low solubility. The smaller molecules C5 – C7 have high volatility (low boiling point), low viscosity and not soluble to any great degree – can be remediated by vacuum vapour extraction. Larger molecular weight molecules (>C9) are not so volatile and viscosity rises with increasing molecular weight – raising the temp with steam helps to vaporise them. Adsorption is proportional to the organic carbon partitioning coefficient. This increases with increasing molecular weight. Chemical oxidation would also be applicable.

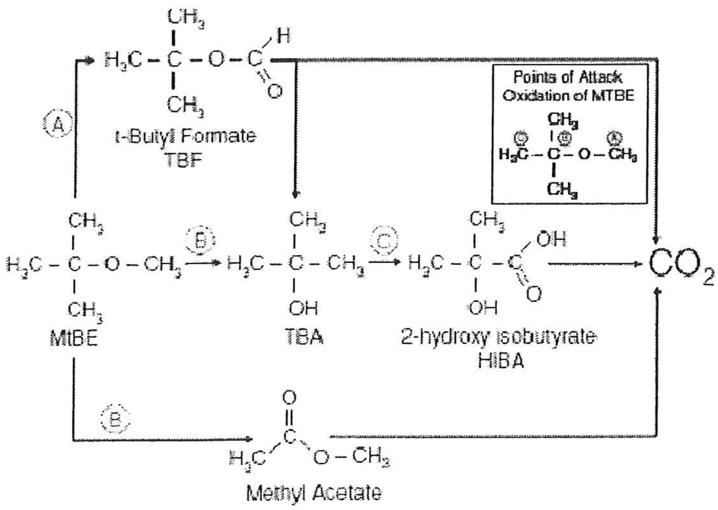
MTBE has low density, high vapour pressure (low boiling point), low viscosity, but differs from the hydrocarbons in that it has very high water solubility (about 60 g/l). It does not adsorb much to soil so it moves rapidly with the groundwater and has little retardation, certainly less than the petroleum hydrocarbons. Henry's constant is low (10 times lower than popular hydrocarbons), i.e MTBE prefers to stay in the water. Difficult to remediate. However some vapour extraction is possible, but a little slow. Bioremediation is slow. PRBs are a possibility.

Chlorinated solvents, PCE, TCE, have high density (DNAPLs) and sink in water, so are hard to remediate. They have low viscosity but are volatile (low boiling point), so vapour extraction is possible, especially can use steam to improve vaporisation. Not very soluble so may stay for a long time. They adsorb to soil, so they are persistent. (NB. The latter point was not covered in the notes). Possible remediation techniques include soil vapour extraction and solvent extraction and possibly bioremediation.

3. (b) (i) Chemical oxidation entails loss of electrons leading to higher valence state or addition of oxygen. Oxidation and reduction (redox reaction) occur simultaneously.
Oxidising agents:

- Substances that causes another substance to be oxidised
- Substance that is reduced in a redox reaction
- Typical oxidising agents include hydrogen peroxide (H_2O_2), potassium permanganate ($KMnO_4$), which is cheaper, and Ozone (O_3) (as is gas difficult to use)

For heavy metals: e.g. $As^{+3} \rightarrow As^{+5} + 2e^-$
For organics: Chemical oxidation is highly suitable for compounds such as phenol, aldehydres and amines and has low suitability for highly halogenated hydrocarbons and saturated aliphatic compounds.
Hydrocarbons: C_6H_{14} (Hexane) + 9.5 O_2 $\rightarrow$ $6CO_2$ and $7H_2O$
MTBE: Possible oxidation pathways (expect students to have general idea of what the oxidation will entail rather than know exact resultant compounds)

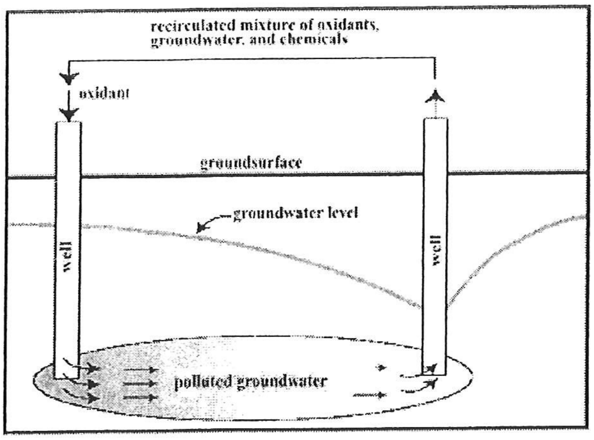


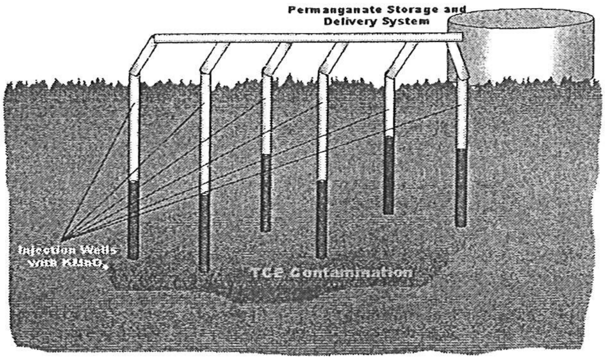
Chlorinated solvents: e.g. PCE and TCE with permanganate

(a) $C_2Cl_4 + 2MnO_4^- \implies 2CO_2 + 2MnO_{2\,(s)} + Cl_2 + 2Cl^-$

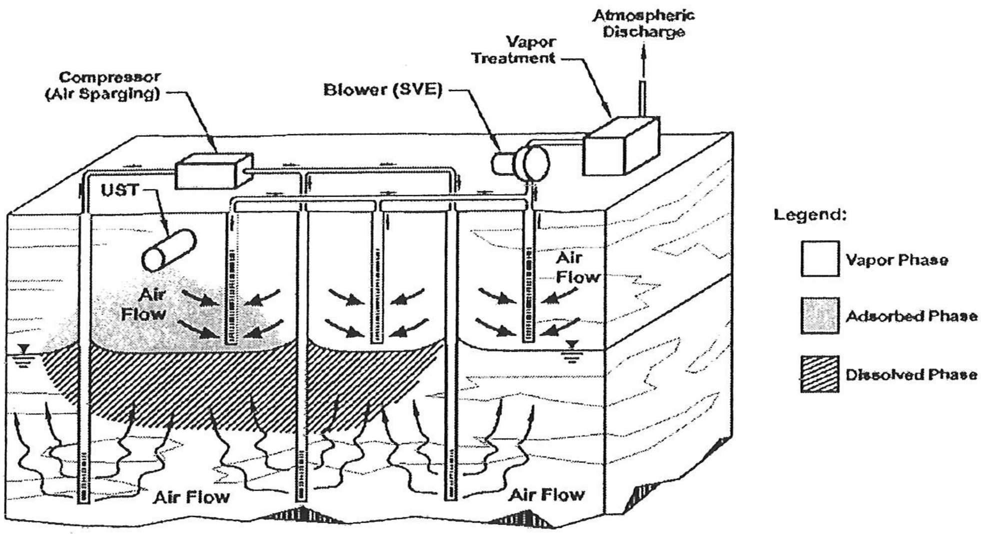
(b) $C_2Cl_3H + 2MnO_4 \implies 2CO_2 + 2MnO_{2\,(s)} + 3Cl^- + H^+$

Chemical oxidation can be applied in-situ for groundwater remediation using wells through which the chemical oxidants can be injected as show in the two sketches below.





(ii) Air sparging involves the injection of compressed air (and occasionally steam) beneath the water table to promote remediation. It is a hybrid technology because it includes both physical & biological remediation processes. The aim is to remediate dissolved-phase of adsorbed organics. Although sometimes used in isolation, more commonly used to extend application of SVE to water-saturated soils. Air will penetrate an aquifer when the air injection pressure exceeds the sum of water column hydrostatic pressure and air entry pressure.



Underlying principles that control contaminant mass removal rates include:

- Transfer of volatile contaminants from aqueous to gaseous phase by diffusion across the air-water interfacial surface area of the air channels during air sparging
- Volatilisation of contaminants from sorbed or trapped phase into air-filled channels
- Aerobic biodegradation by indigenous bacteria

Dual-phase extraction combines vapour and groundwater (and sometimes free product) removal from a single well

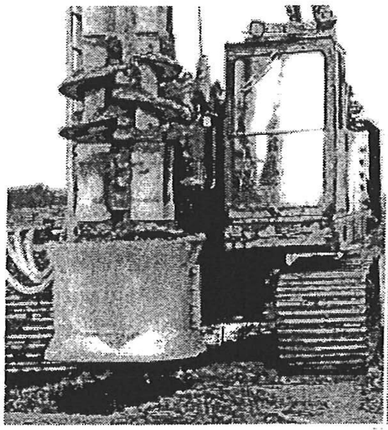
Assessor's comment:

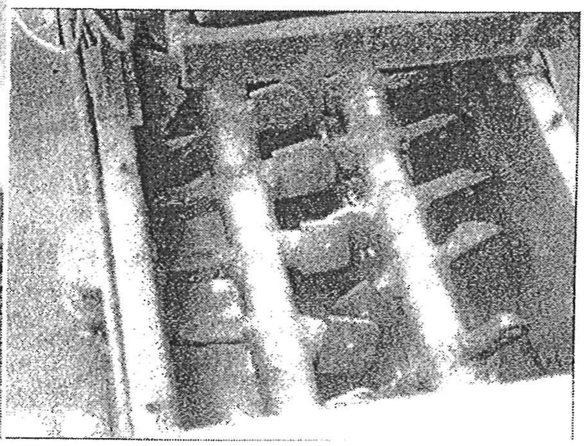
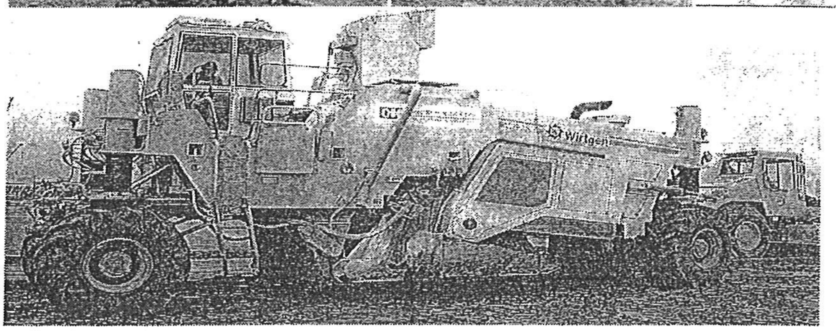
A question in two parts: the first is on the properties of three different organic contaminant groups, specified, that would affect the selection of their remediation technique and the second part is on suitability of chemical oxidation and air sparging in the remediation of those thr› ꞓ contaminant groups. A tricky question because it requires them to connect different parts of the course together and is related to specific organic contaminant groups rather than being general, hence surprisingly was not a popular question. Never the less was answered all by the students who did it.

4 (a) Chemical site investigation usually designed based on desk study and client requirements. Performed to obtain information on potential harmful substance, potential for chemical or electro-chemical attack on construction materials, presence of any combustible materials, emission of toxic flammable gases and their migration routes, presence of phytotoxic compounds, suitable licensed disposal sites for the material on site, whether dewatering operations will require treatment before disposal and advantages/ disadvantages of different parts of the site. Procedure involves trial pits and boreholes: usually trial pits are preferred to boreholes. Trials pits down to 4-5m can be dug. Burried pipes and structures will be revealed and water level noted. Sampling: Concentrate sampling points in areas which the site history, observations and desk study indicate likelihood of contamination and where development is likely to take place. Attention needs to be paid to sampling technique and amount sampled and gas emissions. Samples also taken for geotechnical investigation including strength, compressibility, permeability, compaction etc. Samples taken for chemical analysis include testing for contaminant concentrations, pH, COD, BOD, suitability for various treatments.

(b) Solidification is the process of converting contaminated material into a durable, dense, monolithic entity with structural integrity that is more compatible for storage, landfill or reuse. Stabilisation is the process of minimising the hazardous potential and leachability of contaminated material by converting it into a form which is less soluble, mobile or toxic. Stabilisation/solidification (S/S) is applied mainly with the use of cementitious binders. S/S is far more effective for heavy metal immobilisation. Mechanisms both chemical and physical and include: sorption (adsorption/absorption), precipitation and lattice incorporation. For organics S/S is far less effective with mainly physical entrapment. Special additive such as organoclays can be used to deal with the organics.

(c) In-situ S/S involve mixing the binders with the contaminated soil using either deep mixing equipment such as augers and trenching machines, see figure below, or for shallow treatment with the use of backhoes and blenders. Ex-situ is performed with the use of pugmills. Examples shown below



(d) The most common are:

(i) Cement: Most commonly used binder, has been used for decades, Various types of cements, most common Portland cement (PC), consists mainly of tricalcium and dicalcium silicates (Alite & Belite), best suited for inorganic wastes particularly heavy metals, some inorganic and organic compounds problematic for setting and strength development of cement, Immobilisation is achieved by (i) physical entrapment of contaminants within cement paste matrix, (ii) chemical reaction of contaminants with hydration products and (iii) formation of low solubility hydroxides. Additives, such as pulverised fuel ash, and blastfurnace slag are used as partial cement replacement reducing costs and improving effectiveness.

(ii) Lime: Quicklime (calcium oxide) and hydrated lime (calcium hydroxide) most common forms used as binders, lime is used to control pH of waste in range where metals are least soluble, with a compromise when several metals are present. Usually used with PC or a pozzolan.

(iii) Bentonite: Characterised by clay mineral montmorillonite which is a smectite and is chemically classified as hydro-alumino-silicate, has high water absorption potential, swelling properties and cation exchange capacity (CEC) due to its large surface area, has high capacity for contaminant adsorption e.g. heavy metals, has very low permeability, providing a physical barrier and high liquid and plastic limits providing a flexible material, modified clays (organophilic) are natural clays with increasing organic adsorptive capacity through chemical treatment, Can be used alone or with other binders like PC

(e) Advantages:

- Conventional equipment and readily available materials are used.
- Hazardous properties of the contaminated materials are reduced in the short-term
- Handling or engineering properties of the treated materials may improve
- Relatively straight forward to integrate with regimes such as incineration

Disadvantages:

- Difficult to select a suitable reagent if a complex mixture of chemicals is present
- Long-term performance is uncertain
- Volume of material to be handled may increase
- Monitoring may be required

(f) Effectiveness of S/S usually conducted using leaching tests. These include batch leaching (on broken down granular material) and tank leaching (on monolithic materials). The leachate levels have to be below the design requirements. The strength is also usually measured as it is an indication of the effectiveness of the treatment. The design criteria are based on the application of the treated material which could be landfilling, redevelopment of a contaminated site or reuse of the end product as aggregate in construction.

Assessor's comment:

A question on a specific contaminated site and its remediation using in-situ stabilisation/solidification, with 6 parts covering design, construction and sustainability aspects. Apart from a few completely wrong or missing answers, the main problem with the answers provided was that many were just too brief; some consisting just of one short sentence of 5-6 words!