M

ENVIROSERV
WASTE MANAGEMENT

31st October 2016

The Department of Environmental Affairs

To whom it may concern,

Re: Investigation of odour generation at Shongweni landfill and evaluation of possible mitigation measures

Summary

Historically, EnviroServ's Shongweni landfill has experienced few to no complaints regarding odours. However, from April 2016 there has been a significant increase in odour complaints registered at the Shongweni landfill site. These complaints originated mainly from the wider Hillcrest and Plantations Estate area and to a lesser extent from other residential areas within a five kilometre radius of the facility.

GeoZone, an independent air emission monitoring specialist company appointed to assist in the identification of potential sources of odour, confirmed that elevated levels of hydrogen sulfide (H_2S) gas above the odour threshold limit were being detected at the fence line of the site. Consequently, a thorough review of all loads accepted at the facility as well as any other operational changes that could potentially be contributing to an increase in odours being generated was conducted.

The leachate generated by the waste body in Shongweni's recently commissioned cell in valley 2 was identified as a significant source of hydrogen sulfide (H_2S) and various mitigation measures were immediately implemented to try and reduce the impact of this odorous gas while the cause of the sudden increase in the generation of the H_2S was investigated. Details of the steps taken

to mitigate the H_2S are provided in the text of this document, however, these increasingly show that the point of generation is not only the leachate collection and treatment systems in place at Shongweni, but includes the landfill itself.

The cause of the sudden increase in H_2S generation is attributed to the change from the previous waste management regime in place at the site, namely the **Minimum Requirements for Hazardous Waste Management**, to the newly promulgated **Waste Regulations**. This change in legislative environment brought with it a change in the pH regime used to manage waste (from significantly or highly alkaline to a more moderate lower alkalinity), which has triggered the rapid growth of sulphur reducing bacteria (SRB) in the site that release hydrogen sulfide (H_2S) gas in their lifecycle decomposition of sulphate bearing wastes.

In this context, the optimal solution to returning the Shongweni site to its previous state of low odour generation is seen as being linked to a pH regime that is maintained at pH>9 for all waste streams received and the passivation of the SRB by also increasing the internal alkalinity of the site to pH>9. The SRB are widely published to have reduced activity at pH>8.5, while the higher alkalinity will also have the added benefit of capturing any acidic hydrogen sulfide (H_2S) gas already present in the waste body and preventing release to the atmosphere. It is believed that these measures will reduce the amount of hydrogen sulfide (H_2S) gas produced and released by the site and thereby prevent any odour issues related to this pollutant.

Discussion

1. Shongweni – Valley 1 versus Valley 2

The Shongweni landfill site has been in operation since 1992, initially under the auspices of Waste Tron (valley 1 - cell 0) and from 1997 onwards under the management of EnviroServ (valley 1). Until 2010, all wastes received at the site were disposed of into valley 1 of the site as designated on the site plan and as approved in the site permit. All wastes received into this valley were also managed according to the conservative waste management regime advocated by the **Minimum Requirements**[1] and as mandated by the sites' permit[2].

[1] The waste management series. Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste, 1998. as published by the Department of Water Affairs & Forestry
[2] Permit number 16/2/7/U602/B3/Y1/P270 (Amendment to Permit No. B33/1/1920/P71)

Valley 2 (cell 1) was commissioned in 2010 and began receiving wastes in July 2010. The initial loads received by cell 1 in valley 2 were still classified and treated as per the **Minimum Requirements**, however, as of December 2013 EnviroServ commenced to integrate the waste management protocols of the **Waste Regulations** into its landfill practices at the Shongweni site.

In this context it is important to note that all wastes received into valley 1 were required to comply with the landfill load limit restrictions for various risk elements as described in the **Minimum Requirements** and the concept of "*Total Load*", whereas all of those received in valley 2 have as of December 2013 been under the conditions prescribed in the **Waste Regulations**[3]. A brief summary of the differences between the waste management protocols of the **Minimum Requirements** versus the **Waste Regulations** is shown in Figure 1 below:

Figure 1: Comparison of Minimum Requirements (1998) and Waste Regulations (2013)

Minimum Requirements	Waste Regulations
From 1998 - 2013	Promulgated 23 August 2013
Landfill focussed	Waste hierarchy focussed
Hazardous & general waste landfill sites	4 classes of landfill, Class A – D; not linked to hazard rating
Hazard class using SANS 10228	Hazard rating using SANS 10234
Conservative leach limits used	Total and leach concentrations used
Landfill load limits applicable	No landfill load limits
Limited documentation required	Hazardous waste requires a manifest and a Safety Data Sheet (SDS) to accompany the waste

Many if not all of the wastes received historically into valley 1 are the same wastes received by valley 2 with the exception of those that were rated as HR1 or HR2[4] under the Minimum Requirements as these were not previously permissible according to the Shongweni licence. The

[3] National Environmental Management: Waste Act, No. 59 of 2008. Waste Classification and Management Regulations (GNR 634), 23 August 2013

[4] Hazard Rating 1 or 2 as defined in the Minimum Requirements. Disposal only allowed at H:H landfill sites.

causal impact of the change in moving from the **Minimum Requirements** to the **Waste Regulations** is therefore believed to be a significant contributor to the increase in odour related complaints linked to the Shongweni site as will be detailed in the next section.

2. Waste management - Minimum Requirements versus the Waste Regulations

The conservative approach to landfill disposal of waste adopted under the **Minimum Requirements** (MR) inherently focussed on the reduction of leachability of various risk elements and compounds. To this end, the **Minimum Requirements** made use of a concept known as the "*Total Load*". This is defined in the MR as "*the capacity of a Hazardous Waste landfill to safely accept a substance*" and is based on the leachable concentration of the relevant substance. This is clearly stated in the MR as follows (underline emphasis added by the author):

- "*The **Total Load** capacity of a landfill site will be influenced by the inherent hazardousness of the waste, by the mobility (leachability) of the waste, and by the landfill design (leachate collection system)*".

It was found historically that the reduction of the leachable components in a waste were best achieved by a combination of the techniques described in the MR as "***Immobilisation, solidification and encapsulation***" with "*immobilization*" (*or chemical stabilization*) being a "*process in which the waste is converted to a more chemically stable or more insoluble or immobile form*". Such chemical stabilization was most often achieved through the use of lime or a combination of ash and lime to raise the pH of the treated waste to a pH~9 and convert most soluble / leachable risk elements to the more insoluble elemental oxides. Clear evidence of such chemical stabilization (or chemical treatment) could be seen in the pH of the leachate generated from the treated waste which would, on average, exit the disposal cell at a pH>8 or higher. This is in contrast to the often acidic pH (ie. pH < 7) typically generated by most if not all municipal (ie. non-hazardous) waste disposal sites.

In stark contrast to the management practices adopted under the MR, the **Waste Regulations** have no requirement to monitor the Total Load for a risk element or compound and appears to follow the philosophy that as long as the leach concentration limit for a specific risk element can be complied with, the chosen landfill site can accept as much of the waste, volume wise, as the air space capacity will allow. For a Class A landfill site (or H:H / H:h class as defined in the MR) this would imply that for many waste streams no pH adjustment is required as the upper leach thresholds (LCT3 value) as mandated by the Landfill Norms and Standards[5] are very liberal when compared to the leach standards inherently imposed by the MR. A comparison of the threshold limits [referred to as the "***Acceptable Risk Level***" (or ARL) in the MR] for a few risk elements is shown in Figure 2 below.

Figure 2: Comparison of threshold trigger levels
Minimum Requirements (1998) versus Waste Regulations (2013)

	Waste Regulations	Minimum Requirements
Contaminants in Waste	**LCT3 mg/l**	**ARL mg/l**
Metal Ion Contaminants		
As, Arsenic	4	0.43
B, Boron	200	10
Ba, Barium	280	7.8
Cd, Cadmium	1.2	0.031
Co, Cobalt	200	6.9
Cr_{Total}, Chromium Total	40	4.7
Cr(VI), Chromium (VI)	20	0.02
Cu, Copper	800	0.1
Hg, Mercury	2.4	0.022
Mn, Manganese	200	0.3
Mo, Molybdenum	28	3.7
Ni, Nickel	28	1.14
Pb, Lead	4	0.1
Sb, Antimony	8	0.07
Se, Selenium	4	0.26
V, Vanadium	60	1.3
Zn, Zinc	2000	0.7

For any waste being disposed of under the regime of the MR, whenever the leachable concentration of a risk element exceeded the ***Acceptable Risk Level*** (ARL value), treatment was typically required to ensure that the landfill would not exceed the ***Total Load*** *capacity* for that

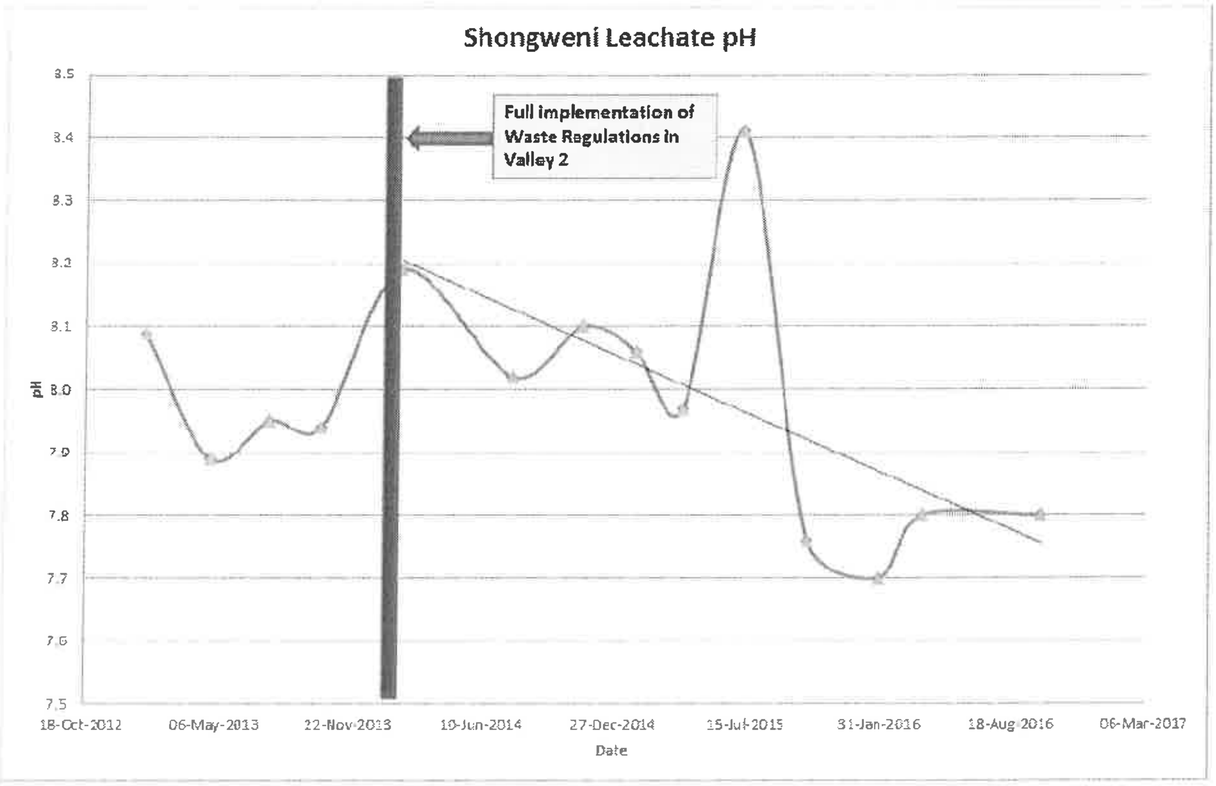
[5] National Environmental Management: Waste Act. No. 59 of 2008, National Norms and Standards for the Disposal of Waste to Landfill (GNR 636). 23 August 2013

specific risk element. This was normally mitigated by increasing the pH of the waste to pH~9 as stated earlier.

The **Waste Regulations** do not have the conservative approach of a Total Load calculation and with the higher leachable levels for risk elements as shown in Figure 2 (LCT3 values), wastes complying with these levels often require no pH adjustment as they readily also meet the pH requirements for landfill disposal, given as 6 < pH < 12. This would imply that under the **Waste Regulations**, many wastes can be disposed to a Class A landfill without any pH adjustment and that as many of these are of low alkalinity (ie. pH tending towards pH7) the pH environment in a landfill will follow the average pH of the incoming waste streams rather than the pH~9 of wastes treated and disposed of under the MR.

Evidence of this slow shift in pH towards the acidic side of the pH scale is evident in the case of the Shongweni landfill when the leachate pH is plotted over time as shown in Figure 3 below:

Figure 3: Leachate pH – Shongweni valley 2 leachate tank



The pH trend line shown in the graph above (circa Dec. 2013 to Sept. 2016) clearly reveals that the pH has been moving from a high of pH8.2 to a lower alkaline value of pH7.8. It needs to be emphasised that this is still well within the pH range required for landfill disposal of waste (6<pH<12), but is particularly relevant w.r.t. the activity of sulphur reducing bacteria (SRB) present in the site.

3. Analysis of waste streams disposed in valley 2

A review of all waste streams received at Shongweni in 2014 (Jan. 2014 – Dec. 2014) as well as Sept. – Dec. 2015 did not flag any significant wastes in the >34 000 waste loads received at the site that could be immediate sources of odour. However, the review did reveal that the site had received large volumes of boiler ash over the period 2013 – 2016 to be used for waste treatment and stabilization in valley 2 and that this material contained ~1.4% sulphates. In this context it should immediately be noted that Shongweni valley 1 had historically received similar volumes of this waste stream (from 2007 onwards) for waste treatment and stabilization with no significant odour issues being flagged or registered. As there are no immediate sources of hydrogen sulfide (H_2S) gas in all of the waste loads received at Shongweni, the only conclusion that can be reached is that the presence of Sulphur Reducing Bacteria (SRB) in the site are responsible for converting the sulphur and sulphates in wastes disposed to the site into the H_2S emissions linked to the site.

The boiler ash noted above, as well as most of the other sulphur bearing waste streams identified in the waste survey, had historically been received at Shongweni landfill (from ~2007 to 2012) without there being any significant odour events. However, it is known that disposal of this waste stream (as well as the other sulphur bearing wastes) into valley 2 was done under a different waste management regime than that used in valley 1 where these wastes had historically been disposed (ie. MR versus Waste Regulations). As noted in paragraph 2 above, the most significant difference between the two waste management philosophies is related to the final pH of the wastes being disposed. For wastes disposed under the MR, the pH of the waste being disposed was typically maintained at pH~9 to ensure compliance with the Total Load philosophy of the MR. However, under the Waste Regulations, the waste is suitable for disposal as long as the assessment under the Landfill Norms and Standards confirms suitability of the site design is appropriate (eg. Type 1 waste must go to a Class A landfill or its equivalent, in this case a H:H or H:h design) and the waste is within the legislated pH range (6 < pH <12).

Many of the wastes received into valley 2 of the Shongweni landfill under the Waste Regulations are within this legislated pH window (ie. 6 < pH <12) but tend to be toward the more acidic side of the scale and as they are Type 1 when assessed, can be disposed without any additional treatment or pH adjustment being required. The disposal of these neutral to slightly acidic waste streams into valley 2 are believed to have resulted in a lowering of the pH in the waste body of valley 2 as evidenced by the change in the pH as shown in Figure 3, creating the ideal pH environment for sulphur reducing bacteria (SRB) to flourish.

The supposition that the pH difference between waste disposed to valley 1 versus that disposed to valley 2 can be linked to increased H_2S emissions is supported by numerous scientific publications on the matter including one published by Al-Zuhair *et al* in 2008[6]. In this publication the authors clearly demonstrate the link between the activity of sulphur reducing bacteria (SRB) and pH as reflected in the growth trend graphs excerpted from their publication and shown below in Figures 4 and 5.

Figure 4: Excerpt from Al-Zuhair *et al* – SRB growth versus pH

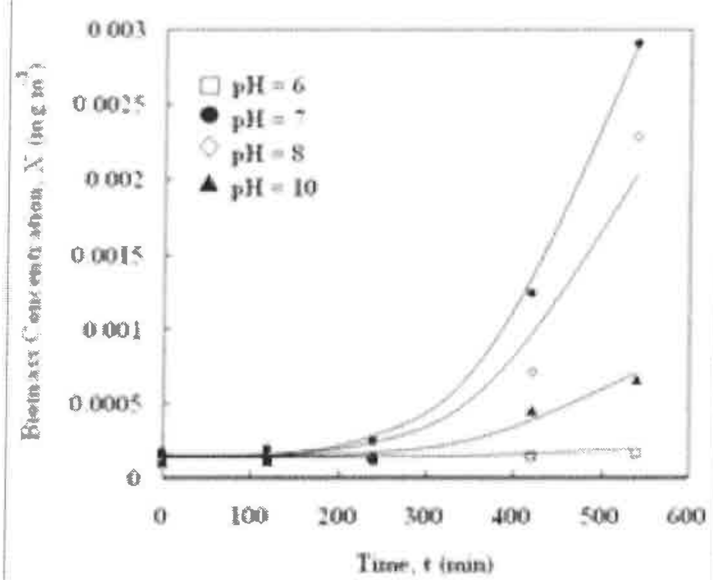


Figure 9: Effect of pH on the SRB growth at 35°C and 2500 gm

[6] Sulaiman Al-Zuhair* . Muftah H El-Naas, Huda Al-Hassani, J Biochem Tech (2008) 1(2):39-44

Of relevance is the rapid growth trends shown in Figure 4 when the pH drops from pH=10 (shown as ▲) to lower pH values such as pH=8 (shown as ◇) or pH=7 (shown as ●). It is also clear from the graph shown in Figure 5 (excerpt from the same publication) that activity of sulphur reducing bacteria (SRB) increases dramatically as the pH drops from pH~9 towards a neutral pH (pH=7).

Figure 5: Excerpt from Al-Zuhair *et al* – SRB growth versus pH

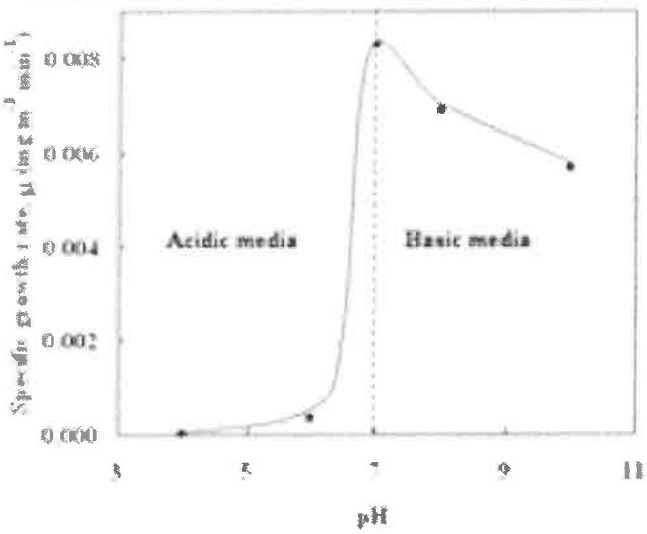


Figure 11: Effect of pH on the growth rate, μ, at 2500 gm and 35 °C

4. Mitigation measures evaluated to reduce H_2S production and emissions

With the acknowledgement that hydrogen sulphide gas (H_2S) is the major contributor to the odour issues linked to the Shongweni landfill various ways to mitigate the emission of this gas to the environment were interrogated.

4.1 Treatment of point sources

The initial supposition that the leachate and/or leachate collection system are the only contributors to the H_2S generated at the site is becoming increasingly unlikely as i) covering of leachate tanks ii) emptying of leachate collection dam iii) treatment of leachate via various oxidative processes have been implemented but odour related complaints are still being registered. After discussion with various experts (Dr Jean Bogner – USA based landfill expert; Dr Richard Daneel – biochemist; Margot Saner – air emissions specialist) there is broad consensus that the whole face of the site is in all likelihood also a diffuse source of H_2S.

This triggered investigation of various options to treat the gas generated in the landfill rather than as various point sources. The options listed below were interrogated as part of this investigation.

4.2 Gas extraction and treatment

a) By means of gas flare

It has been proposed that the hydrogen sulphide gas (H_2S) can be destroyed via a gas flare as implemented at the Interwaste FG landfill site. However, it should be noted that H_2S will be converted to various sulphur oxides including sulphur dioxide (SO_2) in a 1:1 ratio when combusted in a flare system. It is also well known that sulphur dioxide (SO_2) gas is also a potent pollutant with well-known human health impacts. To effectively scrub the flare gas and prevent release of the SO_2 would be exorbitantly expensive and this option was therefore rejected. Various sources of literature also flagged that H_2S is toxic to the Sulphur Reducing Bacteria (SRB) that are generating this gas in the Shongweni landfill and that stripping the gas off the landfill will inherently encourage increased production of the H_2S as its inhibitory impact is removed from the site. This increase in generation would then result in increased volumes of SO_2 being generated by the flare.

b) By means of biofilter

The use of a biofilter to scrub the H_2S collected via a gas collection system was also reviewed. This type of system is known to be effective in removing H_2S but has the same problem as a) above in that stripping of the H_2S will encourage increased production by the SRB as the toxic effect of the gas in the landfill is reduced via the extraction system.

c) Increased air flow converts landfill from anaerobic to aerobic conditions

Jones & Wagener have voiced their concern that inducing increased gas (air) flow through the landfill by installing a gas extraction system could potentially change the landfill from an oxygen starved environment (anaerobic) to an oxygen rich environment (aerobic) and result in an increase in the internal temperature of the landfill to the point where internal combustion of the site could be triggered. This could clearly be a consequence of using either a gas flare or a biofilter and due to the increased risk of fires in the landfill the gas extraction system was rejected.

4.2 Use of bactericide

Discussion with Dr Karl-Heinz Riedel (Sasol) on ways to treat SRB highlighted the following for consideration:

- Aeration (which he agreed after further discussion cannot work in the Shongweni landfill environment due to the issues highlighted in paragraph 4.1 above but clearly could work in the leachate treatment system)
- Providing the SRB with an alternative electron acceptor (he suggested nitrates) which the SRB then preferentially convert into ammonia (which would not be beneficial towards the emissions from the site) rather than converting the sulphates
- Confirmation that pH 6-8 is optimal for growth of SRB and that EnviroServ should try treatment to get outside this pH window
- The use of a bactericide with a short half-life if there is concern regarding the MATD[7] count at the Southern Waste Water Treatment Works (SWWTW) when discharging the leachate generated on the site. It was suggested that DBNPA (2,2-dibromo-3-nitrilopropionamide) would be suitable.

Use of the bactericide was rejected after reviewing the aquatic toxicity of the product which in a SDS available from Dow Chemical is given as "***highly toxic (US classification) / very toxic (EU classification) to aquatic organisms (LC_{50}/EC_{50} <0.1 mg/L) on an acute basis***". This would imply that even minor over dosage of the bactericide into the landfill environment could result in residual material being present in the leachate generated by the site. This would clearly impact the MATD count when disposing of leachate to the SWWTW and incur significant penalties from the municipality due to the toxicity of the effluent being disposed.

[7] Minimum Acceptable Toxicant Dilution - the dilution required to render a sample non-toxic (i.e. no different from the controls of uncontaminated seawater) towards the gametes of the sea urchin *Echinometra mathaei*.

After discussion of the options proposed, Dr Riedel concurred that in the context of the Shongweni landfill environment the idea of using pH to limit/control the growth of the SRB is probably the best option to follow. The reasons for this are outlined in paragraph 4.3 below.

4.3 Treatment of landfill body and incoming wastes by raising pH

A literature survey on the activity and inhibition of Sulphur Reducing Bacteria (SRB) reveals that they require seven (7) conditions to flourish and generate H_2S.

These are given as:

i. Suitable temperature (can be up to 100°C)
ii. Carbon source (if a site has received biomass and other carbon bearing waste streams these would be sufficient)
iii. Moisture (rainfall would be sufficient)
iv. Anaerobic conditions (landfill sites are normally anaerobic)
v. Source of sulphur/sulphates (these could be in the form of various waste streams containing sulphates and/or sulphur which could be as simple and innocuous as gypsum board)
vi. Suitable pH range (optimal pH range is given as pH 4 – 8.5)
vii. Presence of SRB (known to be present in all landfill sites)

Based on the review of operational differences between valley 1 and valley 2 at Shongweni Paragraph 2 above), the only variable easily controlled (and inherently impacted by the move to the Waste Regulations) is pH as none of the others can be readily changed in the landfill body.

To this end the pH of the site and in particular valley 2 will be restored to a pH range unfavourable for SRB growth (pH>9) by treating all incoming wastes to pH>9 as well as applying additional dosages of lime to the site. The increase in alkalinity internally in the waste body due to this procedure will inhibit SRB and hence H_2S generation as well as have the added benefit of scrubbing out the acidic H_2S gas present in the body of the waste. It is well known that the speciation of H_2S at pH>9 results in all of the sulphide being in the water soluble hydrosulfide form and not in gaseous form.

After evaluation of various options to try and control the generation of H_2S at the Shongweni landfill site, it is concluded that pH control of the incoming waste as well as passivation of the SRB by increasing the pH level in the site is the best way to reduce the generation of free H_2S as gaseous pollutant at the Shongweni site.

5 Conclusion

With the acknowledgement that hydrogen sulphide gas (H_2S) is the major contributor to the odour issues linked to the Shongweni landfill, investigation and interrogation of the wastes entering the site as well as what has changed operationally in the site reveals that the gas is produced by Sulphur Reducing Bacteria (SRB) active in the site. The excessive growth of these SRB has been triggered by a change in the pH regime used to manage wastes at the site from the conservative approach used under the Minimum Requirements with its associated Total Load limits, to the more liberal pH approach of the Waste Regulations. This legislated change had the unintended consequence of shifting the pH within the waste body of valley 2 into the pH range most favourable for SRB growth (often given as $6 < pH < 8$) and creating an environment where sulphur and sulphates contained in wastes entering the site are converted into hydrogen sulfide (H_2S) gas, a very low odour threshold pollutant.

The most effective corrective action to mitigate the emission of the H_2S is considered to be resumption of the pH control used for wastes under the Minimum Requirements (ie. all wastes to be treated to a pH>9) and passivation of the SRB by increasing the pH level in the site. This will be achieved via the additional pH correction applied to incoming wastes as well as through the additional dosing of lime to the site to achieve a pH>8.5 on leachate generated by the site.

Dr J.L. Schoonraad