Towards Sustainable Biogas Management: How does South Africa Compare?

Ladouce, M. A., de Bruyn A. and Waggie, F., City of Cape Town, Utility Services Directorate, Solid Waste Management Department, Disposal Branch, 38 Wale Street, Cape Town, Tel: 021 487 2247,
E-mail: margot.ladouce@capetown.gov.za

ABSTRACT

Reliable, accurate and practical protocols for monitoring of biogas at landfill sites in South Africa is a significant component of due diligence for local authorities. Some progress has been made to formulate legislation governing air emissions to enable measurable assessment of pollution parameters relating to various industries and activities.

Within the waste management context, the environmental specific legislation viz National Environmental Management: Air Quality Act (39 of 2004) (NEM:AQA) as well as National Environmental Management: Waste Act (59 of 2008) (NEM:WA) provide the regulatory reform for air quality through reasonable measures for prevention of pollution, ecological degradation and securing ecological sustainable development. The development of norms and standards as well as regulatory measures assist with ensuring minimising harmful effects on human health and the environment as well as improving monitoring and assessment of air quality pollutants and thus reducing the impact on the receptors. In addition , South Africa set monitoring guidelines with the publishing of the Department of Water Affairs and Forestry (DWAF) published “Minimum Requirements for Waste Disposal by Landfill during 1998.

The United States Environmental Protection Agency (US- EPA) and EU Clean Air for Europe Directive) are international regulatory guidelines that assist in realising improved and sustainable measurement and control of air quality.

The paper provides a comparative assessment of the international landfill gas management processes versus the South African approach and determines where improvements can be realised.

1. INTRODUCTION

1.1 Background

1.1.1 Characteristics of Landfill Gas (LFG)

Landfill gas (LFG) is produced by anaerobic bacteria which consume organic matter in the refuse. The LFG is chiefly composed of methane (CH_4), and carbon dioxide (CO_2). In addition, other major gases that may be present include oxygen (O_2), nitrogen (N_2), and water vapour. Simply illustrated in Figure 1 below:

$$C_nH_nO \xrightarrow{\text{Bacteria}} CH_4 + CO_2$$

Figure 1: Simplified reaction of the methanogenesishere C_nH_nO represents the decomposable fraction of the waste.

LFG usually also contains traces of hydrogen (H_2), ethane, and many other trace gases including volatile organic compounds (VOCs). Oxygen and nitrogen are usually present because of air in the landfill and eith during placement of reuse form the atmospheric weather effects, because of LFG system operations of by diffusion of air into the landfill. Table 1 below provides a typical characteristics of LFG (NREL, 1997).

Table 1: General range of LFG characteristics (NREL, 1997)

Compound	Molecular formula	Approximate % by volume (All are stated on a dry basis except moisture)
Methane	CH_4	45 – 58 %
Carbon dioxide	CO_2	32 – 45%
Nitrogen	N_2	0 – 3%
Hydrogen	H_2	Trace to 5% plus; generally less than 1%
Hydrogen Sulphide and other sulphur compounds	H_2S	Varies by landfill (nominally 10 -200 ppm)
Oxygen	O_2	Less than 1%
Volatile Organic Compounds	VOC	Less than 2 %, typically 0.25 – 0.50 %

The above table represents a typical characteristic. A difference in characteristics does not necessarily mean there is a problem. However a large disparity should be looked at closely.

1.1.2 Significance of monitoring of methane gas

CH_4 is a recognised greenhouse gas, which plays a large part in global warming as it results in far greater global warming than gases such as CO_2. (it is said to have 21 times more global warming potential than CO_2) Landfill sites can produce large volumes of CH_4 that is usually vented into the atmosphere.

CH_4 is also flammable and explosive at concentrations of 5-15% by volume in air. The lower limit is referred to as lower explosive limit (LEL); the upper limit of 15 % is referred to as the Upper Explosive Limit (UEL). The auto-ignition temperature of methane is 540 ºC and walking across a carpet in leather shoes creates a static charge sufficient to ignite methane. The specific density of CH_4 and CO_2 respectively are 0.55 and 1.55 and that of LFG is closer to that of air. For structure protection it is recommended that LFG composition be assessed for its behaviour and no assumptions should be made regarding its similarity to natural air (NREL, 1997). Methane is colourless and odourless and hence it should be carefully managed. LFG has its own characteristic odour due to trace compounds in the gas, but this may not always be exhibited since the movement of the gas through soils could strip off the odour compounds such as sulphur, organic acids, solvents etc. (NREL, 1997).

The gas is usually saturated with moisture and is corrosive. If not properly monitored and controlled, landfill gas can give rise to flammability, toxicity, asphyxiation and other hazards as well as vegetation dieback (EPA,2006).

Various meteorological factors such as barometric pressure, concentration and temperature gradients as well as geological factors specific to the location of the landfill contribute to the species composition, flow rates and concentration of landfill gases generated. These have the potential to migrate laterally vertically through the surrounding soils and can impact various receptors in its vicinity, (Nastev, et.al, 2001). The importance of management of CH_4 concentrations and migration at the disposal facilities can therefore not be sufficiently emphasised.

1.2 National Legislative requirements

1.2.1 Constitution

Environmental rights are duly recognised and respected in terms of the South African Constitution (Act No. 108 of 1996), which reaffirms that everyone has the right-

- to an environment that is not harmful to their health or well-being; and
- to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that-

(i) prevent pollution and ecological degradation;
(ii) promote conservation; and
(iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.

The South African legislative context therefore makes provision for a plethora of environmental legislation, and is structured to include the overarching National Environmental Management Act (Act 107 of 1998) (NEMA). Specific environmental management acts include but are not limited to the following list:

Table 2: Applicable legislation and the specific environmental management acts relevant to waste

Legislation	Relevance to Waste
NEM: Air Quality Act (Act 39 of 2004) 1. GN 1210 of 2009 2. GN 893 of 2013 3. Regulation 827 of 2013 4. GN 172 of 2014	1. SA Ambient Air quality standards – particular relevance to waste management is particulate matter requirements. 2. Amended the list of activities in terms of NEM:AQA which result in atmospheric emissions that have or may have a significant detrimental effect on the environment, including health, social conditions, economic conditions, ecological conditions or cultural heritage published under Government Notice No, 248, Gazette No. 33064 dated 31 March 2010, in terms of section 21(1) (b) - specific relevance refers - the thermal treatment of general and hazardous waste as listed activities. 3. New National Dust Control regulations in terms of NEM:AQA - dustfall thresholds specific to the type of area in which the activity is being conducted. 4. Declaration of greenhouse gas (in particular CH_4 from landfill sites) as priority pollutant.
NEM: Biodiversity Act (Act 10 of 2004)	Protection of critical biodiversity areas, management of these and environmental processes to be followed when activities have the potential to impact these areas.
NEM: Waste Act (Act 59 of 2008)	Various activities which require environmental processes are noted, more recently the introduction of norms and standards for certain lower impact activities, classification of waste as well and guidelines to manage waste activities more responsibly.
National Water Act, (Act 36 of 1998)	Pollution prevention, reporting of incidents relating to natural water resources and water use licence applications where required depending of the type of activity listed as part of section 21 of the NWA.

The above specific environmental legislation assist with the management of the impact of waste activities which results in tighter controls and more effective management of transgressions where these can potentially occur. The overarching NEMA therefore guides the practices according to principles set out in NEMA, Chapter 1, Section 2 and key principles which are relevant to waste management include but are not limited to the following:

- Duty of care
- Pollution prevention
- Polluter pays
- Precautionary principle

The objective is therefore to ensure that responsible landfill management includes these principles and provide sufficient tools for the effective implementation of measures to monitor and control potential impacts.

1.2.2 Department of Water Affairs and Forestry, Minimum requirements for waste disposal by landfill (Minimum requirements), 1998

Air Quality Control and Gas Management Requirements are stipulated in the Minimum Requirements for Waste Disposal by Landfill, 1998, Section 8 (and also in the draft version, 3rd edition, 2005 which was never authorised).

The documents state that gas monitoring is a minimum requirement at all hazardous and large landfills. Monitoring systems must be installed whenever potential gas problems exist. These must be monitored at three monthly intervals during the operation and at the discretion of the Department (which refers to the competent authority) after site closure. The following guidelines are stipulated:

Table 3: Minimum Requirements CH_4 concentration guidelines (DWAF, 1998)

	CH_4 concentration at Standard Temperature Pressure (STP)	CH_4 LEL Limit	Action to be taken
Soil gas concentration	> 1% by volume	20% of LEL	Department must be informed
Inside buildings	> 1% by volume	20% of LEL	Building evacuated
Air Concentration	0.1 to 1 % by volume	2 to 20 % of LEL	Regular monitoring instituted
Landfill boundary (surface and well)	> 5% by volume	100% of LEL	Permanent venting system implemented
Landfill boundary (surface and well)	0.5 to 5% by volume	10% to 100% of LEL	Regular monitoring instituted

The minimum requirements also stipulate the monitoring of VOCs and dust monitoring including speciation of dust samples. VOCs include organic and inorganic substances. Direct measurement using a surface emission isolation flux chamber to characterise area source facilities with hazardous fugitive emissions, has been recommended for use in South Africa. It is recommended that VOC's be monitored at least once per annum at either the well locations or fence line positions.

The Minimum requirements stipulate, through the permit or license conditions, that gas monitoring continues after landfill closure, until the Department is satisfied that landfill gas no longer represents a risk. The period is normally stipulated in the licence or permit and as a general rule is 30 years after closure and rehabilitation of the site. More recently air quality monitoring plans have been approved by the authorities to outline the specific requirements for monitoring based on investigative reporting.

Landfill sites have many sources of dust emissions and variations in meteorological conditions may influence dust concentrations on the site. The Minimum Requirements stipulate that on-site dust at the landfill site be characterised at least once per year, or more frequently when activities on the site may change the dust compositions. It is also preferable to characterise the possible sources of dust on the landfill site in terms of hazardous metals, anions, and semi-VOCs that are normally particulate-associated, and then to model dispersion.

In November 2013, the new National Dust Control regulation (Regulation 827 of 2013) was gazetted, and serves as a further guide for monitoring dust emissions from landfills. This is another requirement of the specific environmental act, NEM:AQA and specifically states that for an area of restriction such as a landfill site which is a non- residential area, the dust fall limits (referring to the dustfall rate (D), measured in mg/m^2/day over 30- days average) may exceed 600 mg/m2/day but should be below 1200 mg/m2/day. Two exceedences above 1200 mg/m2/day is allowed per year, but not in sequential months. . This is quite significant since operations at waste disposal facilities including vehicular traffic can result in particulate matter being generated on a constant basis.

1.2.3 Specific Environmental Management Acts

The NEM: AQA is in the process of being implemented, and during this process certain aspects of previous air quality legislation viz. the Atmospheric Pollution Prevention Act No. 45 of 1965 (APPA) are still applicable to air quality issues.

The NEM:AQA outlines in Schedule 2 the South African air quality standards. The Act includes margins of tolerance, compliance time frames and permissible frequencies by which the standards may be exceeded.

The South African (SA) National Ambient Air Quality Standards were published in the Government Gazette (GN. 1210) on the 24th of December 2009 and are presented in Table1 below. These standards are based on international best practices and indicate safe exposure levels for the majority of the population. The relevance of these standards to waste management refers to the general ambient air quality and specifically the potential impact on receptors in the area. Specifically, the monitoring of particulate matter is important as discussed in Section 1.2.2 above.

Table 4: South African Ambient Air Quality Standards (2009)

Pollutants	Molecular Formula	Averaging Period	Concentration		Frequency of Exceedance	Compliance Date
			µg/m^3	ppb		
Sulphur dioxide	SO_2	10 minute	500	191	526	Immediate
		1 Hour	350	134	88	Immediate
		24 hour	125	48	4	Immediate
		1 year	50	19	0	Immediate
Nitrogen Dioxide	NO_2	1 hour	200	106	88	Immediate
		1 year	40	21	0	Immediate
Particulate Matter	PM_{10}	24 hour	120	-	4	Immediate – 31 Dec 2014
			75	-	4	1 Jan 2015
		1 year	50	-	0	Immediate – 31 Dec 214
			40	-	0	1 Jan 2015
Ozone	O_3	8 hour	120	61	11	Immediate 31 Dec 2014
Benzene	C_6H_6	1 year	10	3.2	0	Immediate – 31 Dec 2014
			5	1.6	0	1 Jan 2015

These standards provide the targets for air quality management plans and a measure of the effectiveness of these management plans. The NEM: AQA provides for the identification of priority pollutants and priority areas which are affected by these pollutants, as well as determining ambient standards with respect to these pollutants and areas. Local authorities are therefore responsible to ensure compliance and compilation of air quality management plans are managed through the municipalities. The cumulative impact, and in particular the contributions by landfill facilities, have more recently become an important aspect to ensure an accurate measurement is achieved.

Another important product of the NEM:AQA refers to the declaration of greenhouse gases as priority pollutant by the Minster during March 2014. It further listed disposal of waste as sources and activities for greenhouse gas emitters. In term of this declaration the landfill site owner should prepare and submit for approval a pollution prevention plan, under Section 29(1) and 57(1) of NEM:AQA (2004).

1.3 International Legislative requirements

1.3.1 US EPA – LFG Regulatory Requirements

The Resource Conservation and Recovery Act (RCRA) Subtitle D was passed in 1974 and various updates have been realised since with the notable recent changes in 1991 pertaining to LFG management. Subtitle D deals with the minimum requirements for landfills. To update RCRA, US EPA added a new section to RCRA, Part 258 which applies to recently closed sites (since October 1993) and currently operating sites. The RCRA standard specifies:

1. Landfill gas may not exceed an accumulation of 25% of the LEL for CH_4 within structures or near the facility.
2. Migrating LFG may not exceed the LEL (5% CH_4 gas by volume) at the property boundary.
3. For landfills receiving waste on or after 9 October 1993, additional gas requirements apply.

The State and local requirements can vary depending upon the State. As a minimum, the State comply with the requirements of RCRA Subtitle D and the MSW New Source Performance Standards (MSW NSPS). They may however have equivalent approved plans.

On 12 March 1996, New Source Performance Standards (NSPS) were promulgated by the US EPA as emission guidelines for their existing Municipal Solid Waste landfills under section 111 of the Clean Air Act (CAA). This was mainly to introduce emission reductions to enable the control of non-methane organic compounds found in LFG at MSW landfills through the application of best systems of emission reductions (US EPA, 2006).

During 1999 a Federal plan was promulgated for the purpose of implementing emission guidelines in states without approved State plans. The Landfill NSPS and Federal plan resulted in emission reductions of over 30 VOCs and air toxins such as toluene, benzene and vinyl chloride. With these reductions direct and indirect benefits with respect to human health and environment were realised. Fire and explosive risks were also reduced due to the reduction in CH_4 gas and the concomitant reduction of odour problems realised the reduced potential of local property devaluations. Improvements in quality of life for residents resulted and the added benefits of energy from landfill gas again realised a source of renewable energy. These guidelines were imperative in assisting with realising the flexibility for landfill owners to ensuring compliance and beneficiating from this activity (US EPA, 2006).

Landfills NESHAP then came about in 2003 through section 112 of the CAA, and although it contained the same requirements as the Landfill NSPS, it further focussed on start-up, shutdown and malfunction (SSM) and operating conditions deviations for out of bounds monitoring parameters relevant to bioreactor landfills and changed the reporting frequency. Further amendments in 2002 focused on clarifying operator, ownerships and modifications of the landfill itself, relating also to gas collection control and treatment systems (US EPA, 2006).

In September 2006, the EPA, proposed amendments to the ‘‘Emission Guidelines and Compliance Times for Municipal Solid Waste Landfills’’ (landfills emission guidelines) and to the ‘‘National Emission Standards for Hazardous Air Pollutants: Municipal Solid Waste Landfills’’ (Landfills NESHAP), and amongst other legislation relative to landfills. They proposed supplemental amendments to the Landfills legislation to clarify what constitutes treated landfill gas and changes to the emission standards (US EPA, 2006)..

In the US context, significant progress already existed about 10 years ago which focused on improving the CH_4 recovery and energy processes and refined specific issues relating to the operations and resource requirements as well as compliance issues, energy recovery and refining and optimising the processes.

1.3.2 CAFE – European Union Directive, 2008

During 2002, the Sixth Community Environment Action Programme adopted by the European Parliament focused on reducing pollution to levels which minimize harmful effects on human health, paying particular attention to sensitive populations and the environment as a whole, and to improve the monitoring and assessment of air quality including the deposition of pollutants and to provide information to the public.

Alignment to the World Health Organisation standards, guidelines and programmes were considered as part of the objectives to ensure pollutants be avoided, prevented or reduced.

A council directive in 1996 focused on management of ambient air quality assessment and management. In 1999 it related this to specific species such as sulphur dioxide, nitrogen dioxide,oxides of nitrogen, particulate matter and lead in the ambient air. In 2000, the council related limit values to benzene and carbon monoxide in the ambient air, and in 2002 related this to ozone.

Several of the compounds contained in the landfill gas are toxic, suspected or confirmed carcinogens and different approaches have been taken internationally. The common factor is that the requirements of the WHO need to be considered and alignment of targets and objectives with WHO requirements are ensured.

1.3.3 European Union – Landfill Directives

A significant milestone in the EU waste policy was released during 1999 and focused on diversion of waste from landfill. This created awareness of landfills impact on the environment and emissions of CH_4 and other gases and pollution of groundwater and other resources. The Landfill Directive set targets for progressively reducing the amount of biodegradable municipal waste landfilled in the period to 2016. In 2009, a decade later, a review was done to engage progress and key lessons for the policy makers in Europe and elsewhere. It was determined that the combination of long-term and intermediate targets provided a good framework for countries to landfill less biodegradable municipal waste. Alternative policies were therefore consulted, which resulted in the amendment of policy where these were required (EEA Report, 2008).

1.3.4 British Columbia Regulations of 2008

The regulations instituted the Landfill gas management regulations and also allowed for the enforcement of certain Greenhouse Gas Reductions (Emission Standards) Amendment Act. In particular it legislated the requirement for owners of landfills to submit an " Initial landfill gas generation and assessment report" which allowed the minister to request further assessment based on the content of the report. Should the owner or operator of a regulated landfill site be estimated to generate more than 1 000 tonnes or more of CH_4 in the calendar year immediately preceding the calendar year of the assessment, they need to ensure that a landfill gas management facilities design plan is ensured. This has to be approved by the director of the department (British Columbia Regulations, 2008).

2. LFG GENERATION

CH4, the main constituent of landfill gas and its global warming potential is produced in significant quantities in the landfill environment, with a typical annual emission figure being about $10m^3$ of gas per tonne of deposited waste. (EPA, 2006)

2.1 Waste management activities - contributors to air quality

The importance of waste management and the rate of landfill gas production is a function of a number of factors including:

- the physical dimensions of the landfill site;
- the types of waste deposited and the associated input rate;
- the placement history (the age and quantity of the waste);
- moisture content, pH, temperature and density of wastes deposited; and
- the application of cover, compaction and capping
- landfill site geology
- maintenance of the anaerobic environment (ie. Little oxygen present in the refuse)
- distance to groundwater
- concomitant landfilling approach

2.2 Estimation of CH_4 from solid waste

US EPA determination of CH_4 contribution from solid waste (anthropogenic contribution) during 2000 showed a 13% contribution, compared to natural gas at 15 % and coal at 8% globally. It was determined that during 2000 the total global contribution of CH_4 to the atmospheric gases was 282.6 (Tg) terragrams CH_4. According to Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004, landfills are the largest anthropogenic source of CH4 at 140.9 Tg of CO_2 equivalents (TgCO2e) emitted in 2004.

Table 5: Percentage municipal waste contribution by province in South Africa, 2011(DEA, 2011)

Province	kg/capita/annum	Total population[#]	Tons per annum	% Organic Waste by Mass	Tons of Organic Waste per annum	Expected CH_4 (m^3)	CO2 E Metric tons[$]
Western Cape	675	5 822 734	3930345	18	707462.2	7074622	17,686.550
Eastern Cape	113	6 562 053	741512	15*	111226.8	1112268	2,780.650
Northern Cape	547	1 145 861	626786	15*	94017.9	940179	2,350.448
Free State	199	2 745 590	546372.4	15*	81955.86	819558.6	
KwaZulu Natal	158	10 267 300	162313.4	15*	24347.01	243470.1	2,048.897
North West	68	3 509 953	238676.8	15*	35801.52	358015.2	895.038
Gauteng	761	12 272 263	9339192	15	1400879	14008788	35,021.975
Mpumalanga	518	4 039 939	2092688	15*	313903.3	3139033	7,847.583
Limpopo	103	5 404 868	556701.4	15*	83505.21	835052.1	2,087.630

* Calculation applied to derive organic component of Municipal solid waste (15%) based on the estimate for Gauteng in 2008 as per NWIBR 2012.

[#] Statistics SA 2011

$ - http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results

Based on table 5, the Tg CO2e emitted during 2011 by landfill facilities in South Africa is approximately 70 TgCO2e which is half that of the US in 2004. Although significantly less is expected for a developing country, this is still significant and should be managed responsibly and the potential for energy recovery as a renewable source should be further explored.

2.3 Movement of LFG and other nuisances

The movement of LFG through the and beyond the refuse is known as landfill gas migration. There are several mechanisms that drive the migration, but two primary mechanisms are:

1. Convection or pressure gradient
2. Molecular diffusion or concentration gradient

Convection is known as the movement from an area of higher pressure to an area of lower pressure. Molecular diffusion is the movement of the gas from higher concentration to lower concentration. It is understood that typically convection causes most LFG migration, however in the absence of a pressure gradient, diffusion may dominate (NREL, 1997).

The subsurface and atmospheric pressure gradient drives the migration of CH_4 gas from areas of high pressure to areas of low pressure (convection). The production of CH_4 during the decomposition of waste materials creates the high pressure conditions required for the gas to migrate to the surface. Relative changes in meteorological conditions such as barometric pressure can also affect the migration of CH_4 by changing CH_4 gas pressure gradients in the subsurface layer, which leads to an increased potential for vertical gas migration into the atmosphere.

CH_4 migration can also occur laterally along preferential pathways where higher permeable native soils are present, or along buried utility corridors filled with aggregate that are coarser than surrounding soils. Gases can move through the landfill surface to the ambient air (diffusion). Once the landfill gas is in the air it can be carried by the wind to the communities. The installation of landfill gas collection and control systems which are operating properly, result in the reduction of migration and minimises exposure of people to landfill gases.

The release of these gases and their constituents to the atmosphere is known to have human health and environmental implications such as carcinogenicity and mutagenicity, air pollution, corrosion of monitoring facilities, fire and explosions hazards. For this reason, the integrated monitoring of landfill gas has been a conventional practise across Europe and North America. CH_4 emissions to the atmosphere or at perimeter locations adjacent to the landfill can occur through a combination of lateral and vertical migration (AWE International, 2013)

Other sources of pollution include the release of particulate matter due to dust generation on landfill sites since the service roads are all gravel. Mitigation is normally through dust suppression and these are normally monitored carefully. Vehicular emissions such as carbon monoxide also contribute to the air quality on the site and should be monitored carefully through an occupational health and safety programme (EPA, 2006).

2.4 Risks, health and safety

The practice of disposing waste to landfill can present a pollution risk and a potential health risk including cancer, respiratory illness and birth defects. In recent years landfills are subject to strict regulatory control which requires sites to be designed and managed such that there is no significant risk to human health and the environment.

The UK, Health Protection Agency have conducted studies in 2011 to inform the risk of exposure to landfill sites. The main potential pathways for exposure of local communities to emissions from landfill sites are through inhalation. If a landfill gas collection and control system is in place and operating efficiently, then exposure to fugitive emissions away from a landfill site should be kept to a minimum (EPA, 2006).

Working with landfill gas requires awareness, alertness, knowledge of the basic safety requirements and common sense (NREL, 1997). The basic safety rules for working on the landfill sites are:

- No smoking or other sources of ignition close to the sources or potential source of methane including structures, vaults, manholes or blower/flare facility.
- Verify that all pressure is relieved before opening any pressurised device or vessel.

- Always strictly comply with electrical lock-out procedures when performing inspection, maintenance or repairs on electrically operated equipment.
- Persons entering confined spaces need to ensure that they comply with the required procedures
- Welding or “hot work” at landfill facilities should be minimised or done off site.
- Any work in trenches or excavated areas need to be strictly controlled through a proper method statement and continuous monitoring must be ensured.
- All excavations or drill borings must be marked and secured and should be attended by an overseer or supervisor for the duration of the work.

A briefing and induction of contractors on site should always be ensured to allow a thorough awareness creation session.

Various occupational risks also exist at landfill facilities however these are not unique to this type of activity or industry. There is a risk of asphyxiation only if the gas is allowed to collect in an enclosed space, such as a basement and at concentrations high enough to displace existing air and create an oxygen-deficient environment. This would be an environment which has less than 19.5% oxygen by volume. CO_2 is denser than air and can escape from a landfill and collect in a confined space. Concentrations of more than 10% can cause unconsciousness or lead to death. Lower concentrations can result in headaches, sweating, rapid breathing and increased heart rate. The concentrations exposed to and period will determine the severity of these symptoms (HPA, 2011).

Migration of landfill gas is possible through buried utility lines and storm sewers on or adjacent to the landfills. Office areas where these structures provide pathways should be carefully monitored (http://www.atsdr.cdc.gov/HAC/landfill/html/ch3.html).

The impact of a landfill site on the microbiological quality of air was studied by Malecka- Adamowicz, et al, 2007 where they studied a landfill site in Poland, situated 4 km south of the outskirts of the town of Bydgoszcz. Eight measuring stations were arranged within the main wind directions, and tests estimated the number of heterotrophic bacteria, mannitol-positive *staphylococci*, actinomycetes and mould fungi in the air. These microbes are normally associated with food and vegetables as well as sewers. Landfill sites may contain saprophytic bacteria, haemolysing *staphylococci*, endospores of aerobic and anaerobic bacterial and numerous fungi which are released to the air. Further to this it is indicated that mycoses of the respiratory system are principally triggered by saprophytes, and these become pathogenic only after they enter a weak host. Malecka- Adamowicz, et al, 2007 noted that airborne microorganisms are more prevalent in spring and summer and less in winter. Cognisance of these health effects should be taken to ensure proper preventative measures are in place.

3. GASEOUS EMISSIONS MONITORING BEST PRACTICE

Landfill facilities, if formally managed and engineered, have a licence or a permit with specific conditions relating to the management requirements. These are referred to as permit or licence conditions. To allow the authorities to arrive at an informed decision, certain background information and specialists’ studies are conducted and this will direct the requirements relating to monitoring of various aspects at a landfill facility. Similarly, when the landfill facility is decommissioned, a post closure monitoring report is generated to ensure that the site is closed responsibly and risks and hazards are identified and mitigated accordingly. Best practice prescribes the compilation and implementation of a proper air quality monitoring plan which needs to be informed by various factors which will be discussed below.

3.1 Frequency

The frequency of monitoring is normally determined by the history of the site and various other factors relating to this. The types of waste, geology of the site and geohydrological characteristics all inform the frequency of monitoring. The potential to impact the receptors in the area will also be a deciding factor on how frequently and what type of monitoring should be conducted.

3.2 Method

Gas concentrations monitored from each probe (a monitoring borehole with the required infrastructure) should represent the concentration of gases in the soils around the screened portion of the probe. In order for gas concentration data to be valid, the functionality of a given probe and the concentrations of gases measured in the probe must be indicative of a subsurface environment. This is achieved by ensuring that the sampling technique and sampling period do not allow for ingress of gases from the atmosphere into the probe. A representative sample should have lower than ambient O_2 and increased CO_2 concentrations.

Aerobic microorganisms in soils deplete the O_2 and release CO_2 within the soil, resulting in higher concentrations of CO_2 and lower concentrations of O_2. This is especially common in the deep probes where O_2 concentrations are expected to be low. Therefore, a decrease in O_2 with depth in probe monitoring is typically considered to be indicative of a valid sample obtained from a subsurface environment. Near atmospheric levels of O_2 in a deep probe, while they can and do periodically occur, is generally indicative of atmosphere leaking into a probe via a crack in the casing, a break in the sampling port/sampling train, or a leak in sampling valve itself (EPA,2006).

3.3 Equipment

There are several types of meters available for gas monitoring.

Meters that utilize infra-red (IR) technology have the ability to measure LEL percentage in air-tight monitoring wells accurately, if properly calibrated. IR meters work from the principle that when the gas interacts with IR radiation, it absorbs a portion of the IR energy. IR absorbance by a gas over a given path length is proportional to its concentration. Some IR meters used to analyze for landfill gas have fixed path lengths to detect CH_4 and CO_2. The advantage of IR meters is that the high CO_2 levels found in landfills will not affect CH_4 readings and they accurately measure in ambient air. Infra-red type meters should be examined, tested, and certified safe for use in explosive atmospheres by a standard method. The International Electrotechnical Commission (IEC) does have such a standard and results in a classification that the meter is "Intrinsically Safe" for use above ground in explosive atmospheres. There are portable IR meters available for use that measure up to 100% by volume CH_4 and CO_2. For oxygen detection, gas is measured by an electrochemical cell. The calibration gas used should be as recommended by the meter manufacturer.
A second type of meter is the Combustible Gas Indicator (CGI). The meter operates through a "hot wire" filament and measures and reports in terms of the percentage of LEL. The meter must be calibrated against known gas concentrations. This type of meter will not measure CH_4 in oxygen deficient atmospheres. CGI meters are not capable of measurements above 100% LEL and will provide erroneous readings when exposed to gas concentrations above 100% LEL. The hotwire filament is sensitive to certain compounds that may be present in landfill gas and can be damaged by them (Yekta, 2009)

Some combustible gas indicator (CGI) test sensors are combined with a thermal conductivity (TC) sensor in a single meter. The CGI/TC meter uses a catalytic oxidation sensor to detect concentrations less than 100% LEL and a TC sensor to measure concentrations above 100% LEL. Meters using a TC sensor do not require oxygen for a valid reading, as combustion of the gas is not required. Depending on the combination of different gases (e.g. CO_2) and their concentrations, values shown on the CGI/TC meter may vary from the actual concentration.

One type is a Flame Ionization Detector (FID). However, this type of meter does not report in percent of LEL and only indicates that CH_4 is present.

Another type of meter is the Photo-ionization Detector (PID). This meter ionizes gas molecules using UV (ultra violet) radiation that produces a current proportional to the number of ions created. But, this type of meter cannot detect CH_4 and is not acceptable for landfill gas monitoring.

3.4 Infrastructure requirements

3.4.1 Monitoring Probe location

When probes are installed, the location of the probe should be clearly recorded on a map with GPS coordinates. It is essential that the probe is not located in the waste body and should ideally be located 20 meters away from the periphery lining. Adequate soil evaluation should therefore be assessed before placing the probe.

In order to minimize the possibility of root intrusion in a probe, the probe location should be placed as far away from deep-rooted vegetation as possible without compromising the ability to monitor for LFG and the probe should be periodically inspected and cleared of vegetation. Probes that are located close to deep-rooted vegetation can experience some degree of root intrusion either in the screened interval or at the joints of the probe. Roots can crack probe casings, block visual monitoring, inhibit depth soundings, and provide a surface for debris build-up (Yekta, 2009).

3.4.2 Monitoring Probe Identification

In order to properly identify monitoring probes at a landfill, the probe should be uniquely labelled. Where probes are located in one well at different depths, this is particularly important in order to distinguish it from other probes. The numbering needs to be consistent and should link into a database where monitoring results are stored for extended periods to do adequate analysis of the monitoring data for trending or modelling.

For wells with more than one probe, the labelling should clearly identify the shallowest to deepest probes. The minimum information on the label should include well identification, and probe identification. (Example:
A well 01 on the northern periphery and shallow depth (N01s) or a well 6 on the southern boundary at intermediate depth (S06i). Probe screen interval is also preferred on the labels.

The labels should be durable and visible for locating and identifying monitoring wells in the field. Non-oxidizing labels are preferred as some metal labels may rust and become unreadable. Labels should be replaced as necessary by the operator to allow easy identification of the wells and probes (Yekta, 2009)

3.4.3 Monitoring probe design

In this section the word "wel| refers to the wellbore and outer protective casing for the borehole probes from where gas monitoring is performed.
Probe refers to the inner PVC pipe lowered into the well and slated to allow landfill gas to enter the pipe for gas monitoring.

Probes should be assembled using materials and in a manner that provides an adequate seal and does not interfere with sampling trace constituents.
Threaded and gasketed assemblies that prevent leaks at connection points or continuous pipe will help ensure that gas samples are collected from the screened portion of a probe as opposed to a leaking slip coupling or screwed together joint. Glued and/or solvent welded joints may also interfere with any trace gas sampling and should be avoided. Some portions of a probe (e.g., end-cap and wellhead) cannot be pre-constructed and, thus, may require a slip-type fitting. PVC is generally used for probes. For PVC, the use of commercially available 5 to 10m sections of pipe is encouraged. Other materials such as HDPE may also be used.

LFG probes should be constructed to allow access by a bore monitor. Probes should have an unobstructed bore interior with an inside diameter of ½ to ¾ inches to allow visual access by a bore monitor (i.e., down-hole camera) (Missouri, 1999).

The EPA requires a certified engineering geologist or registered civil engineer to "field design" the screened interval for the probes and certify installation and completion of wells and probes in the as-builts.

The LFG regulations (Title 27, California Code of Regulations, Section 20923 and 20925) require that

1. the monitoring network is designed by a registered civil engineer or certified engineering geologist;
2. monitoring wells are drilled by a licensed drilling contractor or a drilling crew under the supervision of a design engineer or engineering geologist;
3. wells are logged during drilling by a geologist or geotechnical engineer;
4. the specified depths of monitoring probes within the wellbore are adjusted based on geologic data obtained during drilling and probes placed adjacent to soils which are most conducive to gas flow; and;
5. as-builts for each monitoring well are to be maintained by the operator and submitted to the EA upon request.(Missouri, 1999).

The lengths and depths of screened intervals of probes constructed should be based on subsurface conditions (i.e., lithology, contacts, geologic structure, and ground water) and should consider zones that are the most likely pathways for LFG migration. Correlating the geology to the screened lengths and depths is essential for the effective monitoring for LFG and is considered part of the design of the monitoring network that must be certified by a registered civil engineer or certified engineering geologist. The as-built description should include the rationale for screen placement based on the geology and preferential pathways for migration including placement of mid-depth probe(s)

Probes should be constructed with longer screened segments (as opposed to shorter). The longest screened section practical for the given site-specific situation should be used. For example, within the zone of preferential path (e.g., sand lens), a longer screen encompassing the entire zone is preferred. Longer screened sections reduce the possibility of blockages by bentonite, dirt, roots, and other organic material. In general, screened segments should not be shorter than 1.5m in length. However, in multidepth probes, screened sections should be installed so that they do not overlap at the same depths. In addition, in order to prevent cross-contamination of the ground water by fluids (perched water or LFG), probes should not be screened across confining layers separating perched water zones from the regional aquifer. In very shallow wells, the screened length for probes should be as long as possible without compromising the well seal (Missouri, 1999).

The depth of the probe(s) in relation to the water table should be a design consideration. In order to maximise the effectiveness and life of the monitoring probe, the depth to the water table plus seasonal fluctuations in the water table should be taken into account when determining the depth of the well and screen interval of the probe(s). The screen interval should be long enough so that at least a portion of the screen interval will always be above the water table. An exception to this is when the longer screened interval would overlap with another probe screen.
Wells need to be designed and constructed to prevent cross-contamination of ground water through the well/probes by fluids (perched water or LFG).
Each LFG monitoring well must:

- be properly sealed in accordance with 27 CCR 20925(d) (3) which includes a surface seal;
- seal off any aquitard and/or perch water zone;
- in wells with multiple probes, seal off well between each probe;
- and seal off well just above the high water mark, if a probe will be screened within the fluctuation zone.

Each probe should have only one screened interval. One design option, given no perched groundwater, would be to have a probe that is screened to just above the seasonal high ground water level and a separate dedicated probe screened in the fluctuation zone to the permanent, seasonal lowground water level. Alternatively, the probe in the fluctuation zone could be screened and properly sealed in a separate well (borehole). During high water years or seasons this lower probe may be inundated, but would detect any migrating LFG during dry times (Missouri, 1999).

3.4.4 Probehead Assembly

The probehead design assembly should be designed to allow easy gas sampling and flow testing. The wellhead design should prevent gas from escaping the well into the atmosphere.

Probes should be constructed using a non-specialized valve on the probe head assembly.

The use of a labcock, ball, or similar valve that is easily opened and closed without a special connection or adapter will help ensure that valid pressure and gas readings can be obtained from probes by on-site personnel as well as regulatory agencies. If a specialized or proprietary valve is used, such as a Schrader valve or quick-connect valve, then an adaptor should be provided and stored on-site at the first well or other secure and readily accessible location.

3.4.5 Record keeping

It is important that from the onset of introducing a monitoring plan that the landfill implement adequate record keeping. Data of concern includes locations of probes; construction details and as-built drawings; completion depths; gas monitoring history and well boring logs.

3.5 Resource optimisation

Security is an important aspect in South Africa, since the landfill facilities were targeted in the past for food and waste materials of value. Any infrastructure therefore becomes a source of income for the perpetrators who target the landfill facilities. Although access to the sites is carefully controlled, the sites boundaries can be breached and this is difficult to monitor on a 24 hour, 7 day a week basis.

Monitoring of gaseous emissions at landfill sites is a scarce skill and progress has been made over the last 10 years to improve skills and capacity. It is however still a challenge, but with legislation being rolled out, the anticipation is that this will change and capacity building will be ensured. Sophisticated equipment as discussed in section 3.3 above is costly and sometimes not achievable. Accurate and reliable data is therefore a challenge and with the risks relating to security at the facilities, it seen as a major stumbling block.

3.6 Sophisticated monitoring tools

Recent international research on improving gas monitoring techniques at landfill sites has developed an autonomous platform for monitoring greenhouse gases CH_4 and CO_2 at perimeter borehole wells. The modular design of the technology can also be adapted to monitor gases such as hydrogen sulphide (H_2S), ammonia (NH_3) and carbon monoxide (CO). It is also recommended that the dynamics of the landfill gas management system cannot be captured by taking measurements once per month, and a minimum of once per week is advised. Further, the sampling protocol should be changed to borehole well sampling to a depth of 0.5 to 1m deep, depending on the water level, with an increased sampling time of 3 minutes to obtain a steady state measurement (Breda, et al, 2005).

4. CONCLUSION

The US, Europe and Canada have been active in emission reductions through various greenhouse gas programs as well as legislative requirements and South Africa has followed this process with various CDM projects and landfill gas extraction and electricity. The inception of CDM in South Africa occurred during 2004 and during 2011 approximately 271 CDM project proposals had been reviewed. The pace of CDM in South Africa has therefore been very slow but emission reductions had been realised which can be improved upon (DNA, 2011)

4.1 In South Africa, significant strides have been realised with the introduction of legislation, specifically the NEM:AQA and various regulations and standards relating to this. The challenge currently is that landfill gas management has progressed slowly with landfill CDM projects such as the Bisasar Road Landfill project which is a large scale landfill gas to energy project with the capacity to generate 6.5 MW of electricity. The main restriction referred to in the report by the DNA is the procurement legislation.

4.2 On the positive side the project has realised significant improvements in air quality stated as savings of 240 000 tons of CH_4 in terms of the 2011 reporting. This has a significant positive spin for safety and health at the landfill facililites where where landfill sites exist close to communities, and responsible monitoring is being implemented with the limited resources and where access to funds and skills to address irregularities are also challenges.

4.3 There is sufficient information and literature as well as experience available internationally and this will assist in progressing to a more sustainable biogas management arena. This will however require further implementation and enforcement of legislation. The challenge is to ensure that through a combination of alternative processes such as diversion of waste from landfill as well as, landfill gas to energy projects the management and control of gas becomes an ongoing improvement process.

5. REFERENCES

Atmospheric Pollution Prevention Act 45 of 1965

Breda M. Kiernan, Stephen Beirne, Cormac Fay and Dermot Diamond, 2005, Monitoring of Gas Emissions at landfill Sites Using Autonomous Gas Sensors., Srtive Report, Dublin City University

British Columbia Regulations of 2008, Landfill gas management regulation and Greenhouse gas reduction (Emissions Standard) Statues, amendment act

Department of Environmental Affairs, 2012, National Waste Information Baseline Report

Department of Water Affairs and Forestry, 2e, 1998, Minimum Requirements for Waste Disposal by Landfill.

Department of Water Affairs and Forestry, Draft 3e, 2005, Minimum Requirements for Waste Disposal by Landfill

Designated National Authority (DNA), 2011, South Africa – CDM Status Review

Directive 2008/50/EC of the European Parliament and of the Council, on ambient air quality and cleaner air for Europe, Order number 903

Environmental Protection Agency (EPA), 2006, Environmental Guidelines Solid Waste Landfill, 453R/94/021

EEA Report, 2009, Diverting Waste from landfill, Effectiveness of waste management policies in the European Union, EEA Report no 7/ 2009, Denmark

Health Protection Agency, 2011, Impacts on Health of emissions from Landfill sites

Malecka- Adamowicz, M, Kaczanowska, J and Donderski, W., 2007, The Impact of a Landfill Site in Zolwin-Wypaleniska on the Microbiological Quality of the Air, *Polish J of Environ, Stud*, Vol 16, 101 -107

AWE International, Subsurface Gas Monitoring, Mar 2013.

Missouri department of natural resources. 1999, An analysis of Landfill Gas Monitoring Well design and Construction, Division of Environmental Quality, Solid waste management Program

Nastev, M., Therrien, R., Lefebvre, R. and Gelinas, P, 2001, Gas production and migration in landfills and geological materials, Journal of Contaminant Hydrology, 52

National Dust Control Regulations in terms of NEM:AQA, Regulation 827 of 2013

National Environmental Management Act, 107 of 1998

National Environmental Management: Air quality Act, 39 of 2004 (NEM:AQA)

National Environmental Management: Biodiversity Act 10 of 2004

National Environmental Management: Air quality Act, Government Notice 172 of 2014, Declaration of Greenhouse Gases as Priority Pollutants

National Environmental Management: Air quality Act, Government Notice 893 of 2013, Amended list of activities in terms of which result in atmospheric emissions,

National Environmental Management; Waste Act 59 of 2008

National Renewable Energy Laboratory (NREL), 1997, Landfill gas operation and maintenance manual of Practice, NREL?SR – 430 - 23070

National Water Act 36 of 1998

South African Ambient Air Quality Standards, Government notice 1210 of 2009

South African Constitution, Act No. 108 of 1996

Statistics South Africa, 2011

SCS Engineers, 2008, Landfill Gas Monitoring Well Functionality at 20 California Landfills

US EPA Federal Register, 2006, Environmental Guidelines for Solid Waste Landfill, 453R-94-021

http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results, Accessed on 10 June 2014

www.kolumbus.fi Accessed, July 2007

Yekta, G., 2009, Best Management Practices for Landfill Gas Monitoring Well/Probe Construction, Calrecycle