Sustainable Landfills – Can These Be Achieved?

Peter Novella - MSc(Eng), Pr.Sci.Nat, SFIWMSA
City of Cape Town, Utility Services Directorate, Solid Waste Management Department, Disposal Branch,
38 Wale Street, Cape Town, Tel: 021 487 2477. E-mail: peter.novella@capetown.gov.za

ABSTRACT

What does it mean when one refers to a sustainable landfill? We know that landfills when selected must be properly sited, engineered and operated in accordance with legislation and prevailing regulations.

Landfill is an accepted methodology for waste disposal in South Africa. The regulations that have governed landfill disposal have changed dramatically since 1989 when the Environmental Conservation Act was promulgated and 1994 when the first Minimum Requirements were published.

Sustainable landfills are regarded as landfills where the use air space, biological processes are optimised and the detection of impacts on the environment are negligible. In addition, the use of by-products and emissions in a beneficial manner must be promoted.

Leachate recirculation and treatment along with biogas harvesting and use as well as landfill mining are all processes that can be used to enhance landfill sustainability.

The paper covers various aspects of landfill sustainability and concludes that this is achievable as long as there is a proper understanding of the processes involved.

KEYWORDS

Biogas, carbon dioxide, energy, environment, landfill, leachate, methane, operation, organic, sustainability, stabilisation, waste.

1. INTRODUCTION

Landfill in South Africa is an integral part of the National Waste Management Strategy applied across the country. One cannot implement cleaning, collection and waste minimisation of waste without considering landfill disposal and other treatment processes. In spite of being at the bottom of the desirability hierarchy landfill remains a vital component of effective integrated waste management in South Africa. Without properly designed, constructed and operated landfills environment friendly waste management is not possible.

There are a number of major environmental threats associated with landfills. One is the threat to the environment from landfill leachate whilst another is the release in an uncontrolled manner of biogas. Leachate is a strongly polluted liquid that comprises moisture contained in the waste at the time of landfilling, rainfall percolating through the landfill; moisture added during co-disposal as well as biologically produced liquid. Biogas usually contains high concentrations of methane gas which has a global warming potential (GWP) of 21 times that of carbon dioxide. The United Nations Framework Convention for Climate Change (UNFCCC) has increased the GWP in certain cases to 25. In addition methane gas can cause explosions or asphyxiation and is often the source of fires on landfills.

Many landfills in South Africa are considered as non-leachate producing landfills. These landfills would be very dry and as such the biological processes required to achieve stabilisation will have been retarded, with the landfill requiring extended periods of many decades to reach a stable state. Thus the inherent potential to pollute the environment will remain a reality for long periods of time. In addition the absence of biogas from certain dry landfills does not necessarily indicate that the landfill does not pose a threat but could be due to the fact that stabilization has been retarded.

2. SUSTAINABILITY

Sustainability is often misunderstood. There are a number of differently worded definitions which do cause confusion. One must consider the inter-relationship of the environment (environmental factors), people (social factors) as well as the economy (financial factors). If any of these three groups of factors are at risk of not being fulfilled then the system cannot be regarded as sustainable.

One such definition of sustainability is "*existing and solving today's problems in a responsible and environment friendly manner thereby not prejudicing the ability of future generations to exist or solve their own problems*".

In a waste management perspective one often refers to a cradle to grave approach as being a sustainable approach, however, without considering the stabilisation of waste within a landfill sustainable waste management cannot be achieved. The waste within a landfill must be stabilised within "one lifetime" thereby ensuring that no negative effects or risks associated with a landfill are passed on from one generation to the next.

3. LANDFILLS IN SOUTH AFRICA

The Environmental Conservation Act of 1989 (RSA, 1989) was promulgated in order to provide effective protection and controlled utilisation of the environment. This introduced amongst others new requirements for the disposal of waste. In order to implement this Act, the Minimum Requirements Series (RSA, 1998) was produced in 1st edition in 1994 and as a 2nd edition in 1998, to assist in achieving compliance with regard to landfill permitting, siting, design, operation, monitoring as well as rehabilitation and aftercare.

In 2008 the National Environmental Waste Act (DEA, 2009) was enacted and this further enhanced waste management in South Africa. For the first time the entire waste management process was covered by an Act. Alternatives to landfilling were proposed and the waste hierarchy became a key indicator.

In addition, landfill management which remained in an unsatisfactory state also received further attention when a system of waste licenses replaced the previous landfill permits with the introduction of waste classification and management licenses (DEA, 2013a). This moved away from the waste classification processes of the Minimum Requirements and a new waste classification system was introduced. Landfill classification was also amended from the Minimum Requirements classification system of G and H landfills to a new set of classes viz. class A (hazardous), class B (general) and class C (communal). Certain sections of the Minimum Requirements have now been replaced by the new Norms and Standards for assessment of waste for landfill disposal (DEA, 2013b) as well as by the Norms and Standards for disposal of waste to landfill (DEA, 2013c).

In an article (Oelofse, 2014) the new regulatory requirements landfills are explained. It is concluded by Oelofse that as a result there is now stricter control of waste management in South Africa as well as for the establishment and operations of landfills. The most drastic change is the introduction of stricter assessment of waste for landfill with more complex analytical procedures that is costly and has to be performed at accredited laboratories.

The time taken to achieve compliance of landfills across South Africa under the Minimum Requirements has been very disappointing and in certain areas waste disposal remains in dire straits. However, the implementation of these new Waste Act improvements over time must surely result in improved waste management and more sustainable landfill processes.

4. LANDFILL BIOLOGY

The theory relating to landfill stabilisation is not new. There are 5 distinct phases of degradation viz. aerobic, acid, transition, methanogenic and maturation (Farquar and Rovers, 1973; Pohland *et al*., 1983). The processes that occur during these different phases include the biological fermentation of carbohydrate, lipid and protein substrates (commonly grouped together and referred to as organics).

- Phase1: The aerobic phase occurs until all the air entrapped during the landfilling process has been used up. This phase is relatively short in compacted landfills.

- Phase 2: The transition phase commences fairly rapidly which leads into the third acid forming phase.

- Phase 3: Acid forming phase where complex organic compounds are reduced to simpler shorter chained organic molecules including the short chain fatty acids produced in the acidogenic and acetogenic processes.

- Phase 4: The methane fermentation phase (methanogenesis) begins and continues for many years. When most of the anaerobically biodegradable organics have been degraded (used up) methanogenesis slows down.

- Phase 5: The landfill enters the maturation phase during which methanogenesis continues but at a much slower rate. This phase is slow and can last a decade or more.

The rate at which all these phases occur as well as the time span of the overall stabilisation process depends entirely on landfill conditions. These conditions include amongst others type of bacteria present, type and biodegradability of the waste substrate (organics) and the presence of nutrients, presence of toxic substances, pH, temperature and moisture content.

5. SUSTAINABLE LANDFILLS

What is a sustainable landfill? Landfills can be regarded as sustainable if air space, processes, use of products and residues are at an optimum and where no negative effects on the environment are detected. Landfills can only be sustainable once they are managed to achieve full stabilization in the shortest possible time. This time can be regarded as complete stabilization occurring within one generation.

Leachate recirculation is a process that can be used to enhance landfill stabilisation. Novella *et al.* (1997) shows that the flushing out of excess acids from the landfill can be used to decrease the time needed to achieve methanogenesis whilst the acid leachate derived from this process can be recirculated onto methanogenic waste and be treated in this process with the methanogens generating additional methane rich biogas. Similarly when methanogenic leachate is recirculated onto fresh waste it has been shown to stimulate the onset of methanogenesis in the acid refuse. Liquid manipulation strategies can therefore be highly effective landfill management options to achieve enhanced stabilisation and reduce the time needed to completely stabilise a landfill.

The principles outlined above are those which need to be applied in bioreactor landfills. Karthikeyan and Joseph (2010) point out that the underlying principles of the bioreactor landfill is that by optimising operational control and the environmental conditions within the waste body (especially the moisture content), more rapid and complete degradation of the waste can be achieved in the shortest possible time. The general objective is to produce a stable waste body within a reasonable time scale and thus ensure that the risk to the environment will be at an acceptable level if a liner failure occurs.

Cossu *et al.* (2001) has found that in spite of enhanced stabilisation techniques the potential to pollute may remain in landfills. The utilisation of a combination of processes as in the PAF model (pre-treatment, semi-aerobic and flushing) could optimize the advantage of all the proposed advanced strategies in achieving a sustainable landfill.

Once a landfill has been stabilised the contents can be unearthed, by way of a process known as landfill mining, sorted and all usable items and residues are removed and beneficiated. Kurian *et al*. (2003) state that there are thousands of old landfills and dump-sites throughout developing countries which are a threat for human health. Landfill mining is proposed as a method to rehabilitate the environment through sustainable landfill management especially for developing countries. In this process of landfill mining which includes excavation, screening and separation of the material from landfill into various components including soil, recyclable material and residues, landfills can be rehabilitated and suitably engineered for future use as new landfills that have been designed correctly in order to achieve the sustainable landfill bioreactor.

After the mining process, the remaining unwanted waste material left over could be used to manufacture refuse derived fuel (RDF) and the balance re-landfilled into engineered cells. In this way old landfills that are posing a threat to humans or to the environment can be recycled and the landfill airspace can be recovered and utilised more than once thereby extending the workable life of the landfill.

6. BIOGAS MANAGEMENT

The most important greenhouse gas emitted from landfills as part of the biogas formed during waste stabilisation is methane (CH_4) gas. Landfill gas will continue to be emitted during the entire stabilisation phase and for dry landfills this could last for many decades. In the past landfill gas was managed because of its CH_4 content which is explosive when in contact with certain concentrations of air, as well as to control odours. This changed in 1997 when the Kyoto protocol was adopted by mainly European countries to work together to reduce Greenhouse gas emissions. This has changed dramatically and by June 2013 there were 192 parties to the United Nations Framework Convention for Climate Change (UNFCCC).

Methane gas is some 21 times worse (21x CO_2 equivalents) for the atmosphere than carbon dioxide (CO_2 is 1 equivalent). The concentration of CH_4 in landfill gas does vary but during the methanogenic process concentrations of around 50% are commonplace. De Mattos (2002) points out that there were only 5 flaring systems in place in South Africa in 2002. Since then even though there has been a slow pace, there has been many more installations completed. Strachan *et al*, (2008) discusses the Durban landfill gas to electricity projects but does warn that some 5 years after the implementation of the first project the reality of gas recovered experienced after projects have been developed is often far less than the expectations of much higher landfill gas (with higher CH_4 content) production during the modelling and planning stages. However it can be noted that landfill gas recovered at the Bisasar Road landfill Clean Development Mechanism (CDM) project has exceeded landfill gas predictions at modelling and planning stages (Couth, 2014).

Thus to achieve sustainability landfill gas will need to be managed carefully in landfills. The most common process is to install a series of vertical and horizontal wells placed in the waste body and extract the gas that is being produced. The extraction rate must be optimised to ensure that biogas being produced is being extracted without drawing air into the system. During this process the landfill body will settle considerably so flexible couplings and joints will be needed to be used to avoid pipeline failure and breakages and accommodate the movement.

The CH_4 rich biogas so extracted can be destroyed by flaring or whilst being utilised as a fuel in a gas engine that drives a generator to produce electricity. The CH_4 gas is thus converted to carbon dioxide (CO_2) which although still a greenhouse gas (GHG) is 21 times less of a risk to the atmosphere.

Carbon dioxide is the primary waste of human activity and much research has gone into reducing CO_2 emissions worldwide. When one considers sustainable landfills then CO_2 which makes up most of the other 50% of landfill biogas must also be considered. There is a huge opportunity for the utilization of CO_2 from landfills and that produced by the combustion of CH_4 in the electricity or heat generation processes. However, one first needs to understand the impact of GHG from waste management activities. Friedrich and Trois (2013) have developed GHG emission factors for the collection, transport and landfilling of municipal waste in South African municipalities. Landfill sites without biogas collection and CH_4 destruction is shown to have of the highest GHG emission factors.

Therefore to ensure that a landfill is sustainable landfill gas extraction and destruction with possible added beneficiation must be an integral part of the planning processes. The CDM (Clean Development Mechanism) is a process by which developing countries can be encouraged to develop systems to enhance CH_4 and other GHG destruction and thereby earn money in the form of carbon credits from developed countries that are able to pay to achieve their own GHG reduction targets. Lee *et al*. (2009) points out that by 2008 the carbon compliance market had reached a whopping US$118 billion being driven by the Kyoto Protocol as well as the EU emissions trading scheme. In this process developing countries who would not be able to afford such processes can now afford to implement CDM projects. Because of the 21 times factor landfill gas projects are very lucrative and popular in order to harness CDM and other carbon trading funding. The system to achieve a registered project is however very time consuming, expensive and complicated. However, more recently due to the world-wide recession the CDM market has diminished dramatically.

Prices for CERs (Certified Emission Reductions) have reduced from over R120 per CER to around R5 per CER in 2013 (http://www.emissions-euets.com/cers-erus-market-as-from-2013).

The use of CO_2 can also be considered as a method to reduce GHG emissions. Industrial use of CO_2 is a possibility as is the utilisation of it in agriculture. The CO_2 gas can be suitably scrubbed after being emitted from landfills to ensure acceptability. Photosynthesis is natural process that uses CO_2. It is the process whereby plant makes use light energy as well as CO_2. This can be harnessed in facilities like hothouses / greenhouses which could be utilised into which CO_2 can be fed as a feedstock - however uptake might not be sufficient to utilise the entire CO_2 from a landfill.

7. LEACHATE MANAGEMENT

Once collected, leachate must be managed and disposed of. Disposal can be off site to domestic wastewater treatment works or by way of on-site treatment at the landfill. Treatment on-site is often considered the preferred option as the problem is contained and solved at the source. Thus treatment on a landfill site is considered to be a closed-loop process, whereby contaminants arising from the waste disposal operations and degradation process are contained and treated at the landfill, within the permitted area under a controlled environment. Treated effluent can be used for irrigation or dust suppression.

Any selected treatment process must be capable of treating leachate reliably and consistently to meet pre-determined standards of effluent quality. It is the usual practice to ascertain what the effluent requirements will be for the specific leachate treatment plant before embarking on pilot studies and design processes.

The use of aerobic processes is well documented, and experience using Sequencing Batch Reactor (SBR) leachate treatment plants using this successful process design are currently operational in the UK as well as several other countries worldwide (Robinson *et al*., 1997).

Novella *et al.* (1999) concluded that based on international experience where aerobic treatment using SBR technology has been applied successfully to both small and large landfills, similar leachate treatment systems, using aerobic processes, have an important role to play in the treatment of leachate at landfills in South Africa.

The assessment of leachate treatability prior to the construction of expensive leachate treatment plants is a fundamental starting point for most leachate treatment projects. Pilot scale trials must be run to confirm whether there are any constituents in the leachate quality which could negatively affect the aerobic biological treatment process.

Experience in extended aeration sequential batch reactor plants in the UK dates back over three decades since the first plant was commissioned in 1982. Similar plants are also being operated in China (Robinson *et al*., 1995) and more recently in South Africa (Novella *et al.*, 2005). An example of an advanced leachate treatment plant is the very large leachate treatment plant at the Arpley landfill in Warrington, Cheshire, England (Robinson *et al*., 2003), which treats up to $450m^3/d$ of leachate containing 2500mg/l of ammonia-N, to standards allowing safe discharge into a watercourse. A similar facility incorporating the latest developments of these processes is operational in Malaysia and has been implemented more recently at the City of Cape Town's Vissershok Landfill.

Nitrification and denitrification is included in the process line-up and compliant effluent with low ammonia-N (after nitrification) and low nitrate-N (after denitrification) can be obtained after treatment using nitrification and dentrification processes.

Adequate leachate management and treatment at landfills is the key to achieving a sustainable landfill. Enhancing landfill stabilisation will result in an increase in leachate however due to limited periods that the landfill spends in the acid phases will result in more stabilised leachate from methanoginic processes requiring treatment.

8. REHABILITATION, GREENING AND LANDFILL CAPS

In order to achieve a sustainable landfill one must ensure that the landfill is rehabilitated in a manner that allows the landfill contents to become fully stabilized in the shortest possible time whilst preventing pollution of the surrounding environment.

Apart from the poor siting and bad operations of landfills in the past, it has been a common practice in the past to close landfills by just locking the gate and walking away. The legacy of poorly managed historic landfills remains a monument to waste managers of the past throughout South Africa. The ECA (RSA, 1989) made it a requirement for the rehabilitation of closed landfills and guidelines for this were developed in the Minimum Requirements (RSA, 1998). Licensing of closed landfills is now common place and there is a thrust in South Africa today to accept the legacy of the past and work towards the licensing, rehabilitation and monitoring of historic landfills. In addition, landfills that are shown to be an environmental threat must be prioritized for rehabilitation. The provision of money to do this is also a problem as in the past no provision was made for rehabilitation.

By taking another step towards sustainable landfills, NEMWA includes provisions for the licensing and rehabilitation of contaminated land. Internationally the rehabilitation of old landfills has long been a priority. Various types of landfill caps have been proposed and many types tested. The key to success is to cap a landfill in such a way as to prevent ongoing pollution but not to halt the stabilisation of the contents. The aim must still be to achieve a fully stabilised landfill that poses no threat to the environment.

Phytoremediation has long been proposed as a suitable method for reducing risks associated with landfill leachates. With careful management, phytoremediation can be viewed as a sustainable, cost effective and environmentally sound option in treating or polishing landfill leachate in a natural way using plants, trees and soils (Jones *et al*., 2006). In this methodology land based systems can polish treated leachate prior to discharge to watercourses or in the treatment of stabilised leachates from older more mature landfills. Tyrrel *et al.* (2001) writes that land based systems utilising existing soil resources at landfills are a successful option for treatment of low strength landfill leachates. The type of vegetation will need to be selected carefully and the irrigation system designed to achieve even distribution into and across the treatment area. One concern is that the sensitivity to salt may cause these systems to fail if salt tolerance levels are exceeded in these vegetated treatment systems.

Reed beds can also be used to treat low strength leachate or polish treated effluents prior to discharge. Reed beds are engineered, lined and stone/gravel filled beds into which reeds (e.g. *Phragmites Australis*) are planted. Leachate is fed in a controlled manner into the bed which allows the liquid to pass through the gravel and root zones slowly. Filtration takes place in the gravel and stone bed whilst oxidation of organic matter takes place in the root zone (Novella *et al*. 2005). The size of the bed and the number of reeds depends on the treatment efficiency required.

Once capped landfills are normally vegetated, managed and monitored. However in a move towards a sustainable end use, landfill caps comprising exposed geo-membranes that contain energy generating photo voltaic (PV) panels are being installed at some landfills. Roberts and Dube (2014) describe the Hickory Ridge Landfill in Atlanta of an example where a landfill that has served the community as a waste disposal facility, after it has reached the end of its useful life has been rehabilitated into a commercial scale solar energy generating facility capable of generating 1MW of power. In this way the facility generates clean and renewable electrical power. The cap design is such that erosion and dust is minimised, positive drainage of storm-water is promoted, cap maintenance is reduced and landfill settlement has been accommodated in the design.

9. MECHANICAL BIOLOGICAL TREATMENT (MBT) AND THE SUSTAINABLE LANDFILL

The use of mechanical biological treatment (MBT) processes is well documented and is widely utilised and a waste disposal technology especially in countries where there is a ban on the disposal by landfill of unstabilised organics. MBT plants are widespread in Europe where a landfill ban on unstabilised organics exists. Thus in developing countries the use of MBT prior to the landfilling of treated residues can be a method to achieve landfill stabilisation in a much shorter time frame than would be the case with the landfilling of untreated wastes.

In the mechanical process recyclables can be removed from the waste stream for beneficiation as recycling material into new products and the use of non-recyclable wastes with high colorific values as a fuel to generate electricity or heat. The remaining residue of mainly an organic nature and biodegradable can be sent to a bioreactor in which by way of anaerobic digestion the energy can be captured as biogas which can be used as a fuel to generate electricity or heat.

The treated residue can then either be landfilled or treated further by aerobic means in order to achieve a product that is fairly well stabilised. This can then be landfilled in a controlled manner. It has been shown however that after treatment in a MBT process there is a fraction of the waste that will still need to degrade and this could cause pollution of the environment. Engineered landfills will still be required but it follows that with the risks of pollution greatly reduced, landfill designs can be less stringent and thus cheaper.

Chackiath and Couth (2009) propose tests that can be utilised to ascertain by how much waste is degraded in a MBT process and how much potential for further degradation remains. Is follows then that biogas that will still be produced will need to be managed by collection and flaring. Similarly although leachate produced will be of a weaker nature it will still contain pollutants that can be considered as contaminated so treatment in a leachate treatment plant or in a waste water treatment works will still be necessary.

10. CONCLUSIONS

So where are we now? Can sustainable landfills be achieved in South Africa?

1 It is quite clear that in the South African context sustainable landfills for the vast majority of areas will remain a far off dream. There are still landfills that do not meet the basic fundamentals of properly managed sites. Minimum Requirements was first published in 1994 (1st edition) and 20 years later whilst portions of these requirements are being superseded by what can be considered more stringent guidelines there are still operating landfill sites that are not yet compliant with the Minimum Requirements.

2 We must continue to strive for sustainable waste management systems taking into account the cradle to grave approach and treating ones waste one's own lifetime. In addition we must embrace the new Waste Act which considers the entire waste chain and looks for alternatives to landfill for those fractions of the waste stream that should not be destined for landfill.

3 Having said this, I believe the sustainable landfill is achievable in South Africa; one can just look at the advances made in certain Municipalities and in landfills run by private contractors. There is best practice all over South Africa in pockets of excellence – the challenge remains and there is a lot of hard work needed. In addition investment is necessary to make sure that every citizen has access to a sustainable environment friendly landfill where their waste can be disposed of and be of no threat to the environment for future generations.

4 Landfills must be properly sited, designed with sustainability in mind and run as a bioreactor. Let the natural biology stabilise landfill contents in as short as possible time (one lifetime).

5 Landfill gas must be harvested and methane must be destroyed and the energy beneficiated into electricity generation or heating and CO2 mitigation must be investigated.

6 Leachate must be treated on site where possible and natural vegetation in reed beds or soils should be used to polish the final effluent prior to release. Phytoremediation can be utilised as part of leachate management strategies.

7 Landfill rehabilitation planning must start when the landfill project is initiated, funding must be made available and design of landfill caps should take into account the need for leachate recirculation and include the possibility of advanced techniques like solar electricity generation.

8 Pre-treatment strategies like MBT can be implemented to pre-treat waste prior to landfilling and so by separate recyclables (not removed by at-source separation) for beneficiation, RDF for use as fuel for energy production and the organic substrate be treated by anaerobic processes to harness the biogas. The residues that have a lower pollution potential should thereafter be landfilled.

9 Education in the waste sector needs to be accelerated – we need well educated and experienced waste managers at all levels. Too many senior educated and experienced waste managers retire or leave the industry without transferring knowledge and understanding to up and coming generations of waste managers. Strategies must be put into place to keep experience and knowledge in the waste sector.

10 Funding needs to be encouraged as neither municipalities nor government departments have the resources to achieve sustainable landfills alone. Big business must be encouraged to get involved and invest in the future environmental sustainability of South Africa. There is money to be made for those who invest in innovative solutions. We need to invest to develop beneficiation of local recycling into local products. Buy South African recycled goods needs to be targeted and the population needs to made aware that purchasing local goods creates jobs here at home.

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