# FULL SCALE LANDFILL LEACHATE TREATMENT IN SOUTH AFRICA: THE USE OF AEROBIC SBR PROCESSES AND REED BED SYSTEMS


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## ABSTRACT

Landfill leachate is known to be a highly contaminating effluent liquid that is produced in and released from landfills. Leachate contains mostly dissolved products from decomposing wastes in the landfill. Landfills producing leachate (B+) and H sites must be lined according to SA legislation (DWAF, 1998). Once collected, leachate must be managed and treated, prior to disposal. Experience in Sequencing Batch Reactor (SBR) leachate treatment plants dates back more than two decades in the UK. Some fifty plants using this successful design are currently operational in the UK as well as several others worldwide. In South Africa, pilot scale studies by both the City of Cape Town and the eThekwini Metropolitan Municipality (Durban) have shown the process to be suitable for treatment of leachates generated in the Western Cape and KwaZulu-Natal. Full scale leachate treatment plants have been constructed, by the City of Cape Town, who commissioned a 80 $m^3$ per day plant at the Vissershok (H:h) landfill during April 2003, and by eThekwini in Durban, where a 50 $m^3$ per day plant was commissioned at the Mariannhill (GLB+) landfill during March 2004. At each site reedbed polishing systems are used to achieve very high standards of effluent quality.



## KEY WORDS

Aerobic, Ammonia-N, Biological, COD, Effluent, Landfill, Leachate, Nitrification, Polishing, Reed Bed, SBR (sequencing batch reactor), Settlement, Treatment

## 1. INTRODUCTION

During the stabilisation process occurring within landfills, the organic fraction of the waste undergoes decomposition by means of numerous complex chemical and biological reactions. A cocktail of intermediate products as well as byproducts are formed during this process.

Leachate is a highly contaminating effluent liquid made up from the moisture generated and released from landfills. It contains mostly dissolved products and byproducts produced during the decomposition of waste in a landfill. This leachate is released from the bottom of the landfill where it is collected on impermeable liners and channeled away for subsequent management, treatment and disposal. In South Africa, in order to protect the environment and in particular water resources, landfills including those general waste sites (G) producing leachate (B+) and H (both H:H and H:h) sites, must be lined in accordance with the Minimum Requirements, (DWAF, 1998). Once collected, leachate must be managed and disposed of. Disposal can be off site at wastewater treatment works or by way of on-site treatment at the landfill. Treatment on-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.

Any selected treatment process must be capable of treating leachate reliably and consistently to meet pre-determined standards of effluent quality. The use of aerobic processes are well documented, and experience using Sequencing Batch Reactor (SBR) leachate treatment plants dates back more than two decades in the UK. More than 50 plants using this successful process design are currently operational in the UK as well as several others worldwide (eg see Robinson and Olufsen, 2004; Robinson et.al.,1997).

Novella *et al.,* (1998) concludes 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.

## 2. PILOT STUDIES

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 are used to confirm whether there are any constituents in the leachate quality which could negatively affect the aerobic biological treatment process.

International treatability pilot studies for treatment plants established in the UK and Hong Kong (Robinson and Luo, 1991; Robinson *et al*., 1992; Robinson *et al*., 1995; Robinson, 1997; Robinson *et al*., 2003) are well documented.

In South Africa, Traut *et al*, 2000 and Strachan *et al*, 2000 have documented pilot studies carried out in Cape Town by the City of Cape Town, and in Durban by the eThekwini Metropolitan Municipality, prior to the design of full-scale plants. Any difficulties in biological treatment due to constituents in the leachate can be identified before major expenses are committed.

In the Cape Town trials, which were run for a period of 30 months, leachate tested was generated from both H:h and GLB+ cells at the Vissershok landfill site. It was reported by Traut *et al.* 2000, that the treatment trials were successful and capable of treating leachates from the Vissershok landfill with relatively high COD values (2000 to 5000 mg/l as O) and high concentrations of ammonia-N (>2000 mg/l ). The process was shown to be capable of achieving complete biological nitrification and denitrification as required. Effluent from the plant was found to contain high values of non-biodegradable COD, although tests demonstrated that these compounds had no detectable toxicity. It is reported (CoCT, 2002) that initial concerns that leachate generated from the hazardous waste cells could be a problem were dispelled. After an initial lag period, during which the ability to treat the COD was developed, the treatment trials demonstrated convincingly that there were no apparent constituents of the leachate that would cause significant inhibition of the biological process.

In the Durban trials run by the eThekwini Metropolitan Municipality, pilot units set up at the Bisasar Road landfill were geared towards assessing the treatability of various leachates from sites throughout the eThekwini Metropolitan Area (EMA). Leachate from the Mariannhill landfill was studied, to obtain valuable data to be used in full-scale plant design. Results showed that complete biological nitrification and denitrification of landfill leachates was successfully achieved inside the same Sequencing Batch Reactor (SBR) unit during the trials, and crucial information for the process design of the full-scale treatment plant at the Mariannhill landfill was obtained. Levels of up to 1000 mg/l of ammoniacal-Nitrogen was completely and consistently nitrified to nitrate-N, and in turn denitrified to be released as harmless nitrogen gas, resulting in only negligible levels of nitrogenous compounds in treated effluent. Sludge build-up was minimal, and sludge wastage proved to be an infrequent occurrence.

A significant benefit from the leachate treatment systems utilising SBR's, as tested in Durban, was found to be the robustness of the treatment processes, which were able to sustain treatment of varying concentrations of pollutants, providing treatment to high standards that would allow safe discharge directly into the natural environment. The Mariannhill pilot SBR displayed minimal adjustments required to maintaining pH-levels as a result of suitable alkalinity levels in the raw leachate. The utilisation of methanol for the denitrification processes, which was utilised to supplement carbon *food source* demands, was shown to be up to twice the generally accepted theoretical ratio of 3:1. Typical nitrification rates, for successful treatment ranged up to 0.040 $kgNH_4$-N/kgMLSS.day, while for COD reductions, removal rates of up to 0.15 kgCOD/kgMLSS.day were achieved.

## 3. INTERNATIONAL SCALE CASE STUDIES

Experience in extended aeration sequential batch reactor plants in the UK dates back by more than two decades since the first plant was built in Bryn Posteg in 1982. A paper (Robinson and Olufsen, 2004) contained in the Wastecon 2004 proceedings outlines experience gained in some of these leachate treatment plants operational in the UK. Currently, more than 50 full scale plants designed by Enviros are successfully being operated in the UK (Robinson *et al*., 1997). An example is the very large leachate treatment plant at the Arpley landfill in Warrington, Cheshire, England (Robinson *et al*., 2003), which treats up to 450$m^3$/d of leachate containing 2500mg/l of ammoniacal-N, to standards allowing safe discharge to a watercourse. Similar plants are also being operated in China (Robinson *et al*., 1995) and more recently in South Africa. A new facility incorporating the latest developments is presently being designed in Malaysia.

## 4. VISSERSHOK LANDFILL, CAPE TOWN, SOUTH AFRICA

The full scale leachate treatment plant at Vissershok (see Plate 1) was designed after carrying out extensive treatability trials as described above. After establishing that the process as planned would treat the types of leachate generated from the GLB+ and H:h cells at Vissershok, the specific design criteria was established. These were:

- To design a plant capable of nitrification only – this was as a result of a decision requiring the final effluent to be of a quality for on-site dust control, rather than for off-site discharge.
- The plant should be able to treat 40m$^3$/d of leachate with COD values of 5000 mg/l and concentrations of ammoniacal–N of 2000 mg/l, and up to 80m$^3$/d of leachate with a weaker strength.
- The plant should have a capability of being extended in size by the addition of a further SBR and reed bed.
- The final effluent would be further treated through "polishing" by passing it through a reed bed prior to utilisation on site for dust control.

Leachate is collected from both GLB+ and H:h lined areas on the landfill, leachate ponds and the cut off wall and is leachate is transferred for storage into a raw leachate storage lagoon. The process design includes raw leachate pumping, SBR treatment, a reed bed dosing balance tank, reed bed and a final effluent holding tank. These units are connected by a series of pipes and the leachate / effluent is automatically pumped at predetermined rates and time intervals from one process to another by static or submersible pumps, selected depending on the application. The entire process cycle takes place over a 24 hour period and is controlled by an operator programmable PLC.

Aeration is provided by three submersible venturi aerators, which operate by sucking air from the atmosphere and injecting it into the bottom of the SBR tank. Two aerators operating at any one time supply sufficient oxygen and mixing for the biological process. The process design caters for both nitrification, and the removal of biodegradable organic compounds not degraded during methanogenesis in the landfill.

**Plate 1:** Aerial view of the Vissershok Leachate Treatment plant in Cape Town.

The process design caters for both nitrification and the removal of residual organics not utilised during methanogenesis in the landfill.

During the first year of operation, which included mostly commissioning the SBR produced vast amounts of foam which has required the addition of antifoam solution on a daily basis for foam control. This has however affected the solids concentration in the SBR and reed bed effluent. It is anticipated that this problem which is common as activated seed sludges become acclimatised to treating landfill leachate.

The plant was commissioned during July 2003, and the results contained in this paper are those gathered during the first year of operation. Table 1 presents average results for quality of leachate, SBR effluent and reed bed effluent, as measured during this period. The relevant general standard for discharge to receiving waters is also given.

**Table 1:** Average results for the first year of operation (July 2003 to June 2004) of the Vissershok Leachate Treatment Plant, Cape Town

| Determinand \ Sample | Raw Leachate | SBR Effluent | Reed Bed effluent | General Standard |
|---|---|---|---|---|
| **COD mg/l as O** | 5637 | 1756 | 1195 | 75 |
| **BOD mg/l as O** | 475 | 161 | 89 | |
| **Ammoniacal-N mg/l** | 1337 | 4.1 | 5.6 | 10 |
| **Nitrite mg/l as N** | 1.1 | 1.8 | 1.7 | |
| **Nitrate mg/l as N** | 12.6 | 1114 | 1020 | |
| **Alkalinity mg/l as $CaCO_3$** | 8839 | 1544 | 1476 | |
| **pH-value** | 8.0 | 7.8 | 8.2 | 5.5 to 9.5 |
| **Conductivity mS/m** | 2192 | 1898 | 1692 | 250 |
| **Chloride mg/l as Cl** | 3387 | 3293 | 2935 | |
| **Ortho Phosphorus mg/l as P** | 12.4 | 13.6 | 12.0 | 1.0 |
| **Suspended solids mg/l** | | 644 | 87 | 25 |
| **Sodium mg/l as Na** | 1872 | 2480 | 2142 | 90>influent |
| **Potassium mg/l as K** | 1355 | 1485 | 1239 | |
| **Calcium mg/l as Ca** | 202 | 155 | 115 | |
| **Magnesium mg/l as Mg** | 166 | 153 | 126 | |
| **Copper mg/l as Cu** | 0.02 | 0.10 | 0.08 | 1.0 |
| **Chromium mg/l as Cr** | 0.17 | 0.16 | 0.10 | 0.5 |
| **Zinc mg/l as Zn** | 0.45 | 0.53 | 0.39 | 5.0 |
| **Cadmium mg/l as Cd** | 0.01 | 0.01 | 0.01 | 0.05 |
| **Nickel mg/l as Ni** | 0.18 | 0.22 | 0.18 | |
| **Lead mg/l as Pb** | 0.02 | 0.03 | 0.02 | 0.1 |
| **Iron mg/l as Fe** | 6.1 | 0.16 | 1.01 | |
| **Manganese mg/l as Mn** | 0.40 | 0.16 | 0.07 | 0.4 |

The results as presented in Table 1 show that the leachate plant is satisfactorily treating the raw leachate. Results of the effluent are in general compliant with DWAFs effluent discharge standards. Some points worth highlighting include:

- The system removes some 79 % of the COD fraction. The effluent COD of about 1000 is not cause for concern, even though it exceeds the general discharge standard value of 75 mg/l. In comparison with municipal wastewaters, leachate generally contains high levels of non-biodegradable (hard) COD, that is unaffected by biological processes, so that the mass that enters equals the mass that leaves the process. Consequently, this fraction does not have any effect on receiving environments. Cossu (1997) confirms this and reports that landfill leachate typically contains high levels of hard COD, with concentrations in the order of 1000 mg/l, and this has been demonstrated at many landfill sites.

- Landfill leachate usually contains high concentrations of dissolved inorganic materials, and thus has a high electrical conductivity. The Vissershok raw leachate has a conductivity of 2192 mS/m. This is not treated in biological processes the reduction observed is probably due to physico-chemical interactions within the SBR and Reed Bed. The high chloride concentration confirms the high conductivity results.

- Ortho-phosphorus ($PO_4$) is controlled in South Africa to cut down eutrophication in water courses. This would be a cause for concern, if treated effluent was discharged off site into receiving waters. Sufficient $PO_4$ is required in the SBR to provide essential nutrients to organisms. A $H_3PO_4$ dosing system is provided to add additional P to the SBR as a nutrient, whenever this is necessary.

- Suspended solids in the SBR effluent and reed bed effluent are considered high. However, this is expected to reduce as the SBR foaming problems settle down, and as reed plants continue to establish.

## 5. MARIANNHILL LANDFILL, DURBAN, SOUTH AFRICA

**Plate 2:** Aerial view of the Mariannhill Leachate Treatment plant and reed bed

The Mariannhill landfill, operated by eThekwini Metropolitan Municipality's DSW (Department of Cleansing and Solid Waste), receives between 550 and 700 tons of solid waste each day. The Mariannhill landfill is a "new generation" lined landfill, having been opened in July 1997. Mariannhill landfill currently generates approximately 30 cubic metres of leachate each day, with the potential to discharge up to a sustained flow of 50 cubic metres per day. Mariannhill serves the disposal requirements of the Western reaches of the EMA, and is expected to be in operation for another 14 years. The landfill was located to text-book standards, being well screened from the public eye by the natural topography, and the established growth of numerous large trees in the peripheral buffer zone. The site is arguably the only operational landfill in South Africa to have achieved National Conservancy Status.

The leachate treatability trials which were conducted, in a joint research and development programme between Enviros (previously Enviros Aspinwall) and DSW from October 1998, demonstrated that Mariannhill Landfill leachate may be treated to high standards, within the limits of the discharge standards required by the Department of Water Affairs and Forestry (DWAF, General Authorisations in terms of Section 39 of the National Water Act, 1998) for discharge of wastewater by irrigation. The findings of the treatability trials have thus allowed DSW, in association with Enviros (UK) to design the full-scale leachate treatment plant at the Mariannhill Landfill. The engineering features of treatment plant are:

- The overall treatment philosophy of the plant is the use of "natural, low cost and robust" treatment processes. This plant, therefore, adopts biological primary treatment processes (aligned to the activated sludge process), and secondary "polishing treatment" by reedbed.

- The treatment plant comprises one Sequencing Batch Reactor (SBR) unit, constructed of reinforced concrete, which is 10m in diameter and 6m deep, with a capacity of up to 432 cubic metres, capable of treating up to 50 cubic metres per day of Mariannhill's leachate. A leakage detection system has been engineered under and around the SBR tank, with an automated detection system (EC probe) to detect any leakage from this tank.

- The treatment plant also includes a lined reedbed of some 280 square metres, which provides "polishing treatment" for the removal of any residual BOD, ammoniacal-N, and solids. The reedbed is lined with an HDPE liner to ensure that treated waters are suitably contained for the growth of the reeds.

- All treated effluent from the SBR process is fed into a treated effluent balance tank, also constructed of reinforced concrete, which supplies a stand-point for the site water tanker, for general irrigation on site for dust suppression.

- All treatment processes are controlled by computer systems which relay information to visual displays on a computer screen. The plant logic is designed to shut off the leachate feed pumps to the SBR and switch to direct feed to the existing sewer line should any significant problems be encountered.

- Raw leachate is supplied from the existing leachate storage tanks on site, which have been constructed within adequate bund walling, and is then fed from a dedicated "feed tank" within the bunded area, directly into the SBR unit by means of flame-proof dosing pumps.

- The SBR contains mixed liquor or biological sludge. Dilution of leachate into the SBR is significant and at all times, the supernatant contents of the SBR is deemed to be "treated effluent".
- Following a sludge settlement time-phase in the SBR, treated supernatant or effluent is discharged by gravity into a treated effluent balance tank. This tank, as previously stated, supplies a water stand-point to allow for the filling of the site's water tanker.

- All treated effluent is to be used on site. Most of the treated effluent from the SBR is utilised directly for the suppression of dust on site, replacing the current consumption of potable/drinking mains water for this purpose. Effluent from the reedbed which has received further treatment, is discharged for irrigation of the vegetation areas of the Mariannhill Conservancy. A significant volume from the reedbed will, however, be lost through evapotranspiration.

- An accurate logging of all discharge volumes and the quality of discharge waters is being maintained, and a water management programme strictly adhered to.

- Table 2 (below) gives typical effluent concentrations of contaminants in leachate, and in SBR and reedbed effluents, as well as the General Standard for discharge as applicable in South Africa.

**Table 2:** Typical maximum effluent quality for parameters of concern for the Mariannhill Leachate Treatment Plant, Durban

| Determinand \ Sample | Raw Leachate | SBR Effluent | Reed Bed effluent | General Standard |
|---|---|---|---|---|
| **COD mg/l as O** | 1878 | <400 | <300 | 75 |
| **BOD mg/l as O** | 695 | <10 | <1 | |
| **Ammonia mg/l as N** | 442 | <3 | <1 | 10 |
| **Nitrite mg/l as N** | <0.1 | | | |
| **Nitrate mg/l as N** | 2.7 | | | |
| **Alkalinity mg/l as $CaCO_3$** | 5343 | | | |
| **pH** | 7.6 | | | 5.5 to 9.5 |
| **Conductivity mS/m** | 1285 | <400 | <300 | 250 |
| **Ortho Phosphorus mg/l as P** | 5.0 | | | 1.0 |
| **Suspended solids mg/l** | | | | 25 |
| **Sodium mg/l as Na** | 914 | | | 90>influent |
| **Potassium mg/l as K** | 1232 | | | |
| **Calcium mg/l as Ca** | 208 | | | |
| **Magnesium mg/l as Mg** | 355 | | | |
| **Copper mg/l as Cu** | <0.01 | | | 1.0 |
| **Chromium mg/l as Cr** | 0.08 | | | 0.5 |
| **Zinc mg/l as Zn** | 0.17 | | | 5.0 |
| **Cadmium mg/l as Cd** | <0.01 | | | 0.05 |
| **Nickel mg/l as Ni** | 0.12 | | | |
| **Lead mg/l as Pb** | 0.09 | | | 0.1 |
| **Iron mg/l as Fe** | 18.6 | | | |
| **Manganese mg/l as Mn** | 0.86 | | | 0.4 |

## 6. REED BED SYSTEMS

In developing and designing reed bed systems for effluent treatment, the natural processes that occur in nature are used in a more controlled way to “polish” (further treat) SBR effluents, and thereby further reduce the risk on the receiving environment from pollutants that may be contained in the effluent from leachate treatment plants, should process failures occur.

Olufsen *et al*., (2000) points out that there are several categories of constructed reed beds that could be used. These include free surface wetlands, subsurface flow wetlands and a vertical subsurface flow wetland. Although there are a number of different reeds that can be used in this application, *Phragmites Australis* is most commonly used in UK applications (Robinson *et al*., 1997) and was chosen for the Vissershok reed bed whilst *Phragmites Australis* followed by Bulrushes was planted in the Mariannhill reed bed. *Phragmites Australis* is readily available in South Africa.

In the Vissershok landfill application, the reed bed also uses a subsurface flow design, which comprises a 330 $m^2$ HDPE lined, 600 mm deep, stone filled bed. *Phragmites Australis* was planted by burying juvenile rhizomes in the stone media. Although not completely successful initially, the rhizomes sent out roots into the stones and shoots from the upper surface into the atmosphere. Sparse areas in the bed were later successfully filled by planting adult rhizomes. The flow pattern is designed in a way which allows SBR effluent to enter the bed at an inlet, which receives a controlled flow from the reed bed dosing tank, allowing a continuous flow through the bed over a 24 hr period. The SBR effluent spreads out and passes slowly through the gravel bed where it comes into contact with the root zones of the reed plants. The reeds transport oxygen from the atmosphere into the rhizome and root zones. In this zone, oxidation of organic matter takes place as well as physical filtering effects in the gravel and root zones, which removes residual particulate matter. Through this natural process further residual biodegradable COD, BOD and solids are removed.

A similar designed subsurface flow reed bed has been constructed at the Mariannhill landfill leachate treatment plant. This comprises a lined reed bed, with 280 $m^{2\ of}$ surface area, and 600 mm deep, which provides “polishing treatment” for the removal of specifically residual BOD, COD and solids. The reed bed is lined with an HDPE liner to ensure that the treated waters are suitably contained for the growth of the reeds. *Phragmites Australis* followed by bulrushes have been planted in the Mariannhill reed bed. The flow pattern and operation is similar to that at Vissershok. The use of bulrushes in the second part of the bed prevents the introduction of *Phragmites Australis* into the sensitive Mariannhill conservancy area.

## 7. CONCLUSIONS

From the above mentioned information and case studies it is concluded that:

- Two full-scale South African case studies have demonstrated that the aerobic biological SBR process can be considered to be an appropriate and effective leachate treatment option for leachates at landfills in South Africa.

- Both the Vissershok (Cape Town) and Mariannhill (Durban) leachate treatment plants have shown that at full-scale leachate has been successfully treated in both the Western Cape and KwaZulu-Natal provinces.
- Pilot plant studies were used prior to design in both cases and should be carried out to assess leachate treatability before full-scale design is carried out.
- The destination/use of the treated effluent needs to be determined prior to process design, in order that appropriate treatment can be provided.
- Suitably designed reed beds can be used to further protect the receiving environment, by providing effluent polishing to achieve additional removal of organic compounds and suspended solids in SBR effluent.

## 8. DISCLAIMER AND ACKNOWLEDGEMENTS

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