Treating Leachate from a Hazardous Waste Landfill to River Discharge Quality

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ABSTRACT
EnviroServ Waste Management is a waste management company that operates the Shongweni Landfill (Class A) situated in Kwa-Zulu Natal and the Nyamasoga Landfill (Hazardous) situated in Uganda near Lake Albert.

The Shongweni leachate has typical CODs of 14,000 mg/l and TDSs of 36,000 ppm. The Nyamasoga leachate has CODs of 10,000 mg/l and TDSs of 21,000 ppm. Both are remote sites without access to municipal sewer and thus required leachate treatment technologies that could generate a final product suitable for river discharge. After various laboratory and pilot plant trials a combination of ultra-filtration and reverse osmosis was selected as the most suitable treatment technology. The combination of membrane technologies offers a robust solution that ensures compliance with the relevant river discharge standards. The Shongweni and Nyamasoga landfill sites subsequently constructed leachate treatment plants in 2016 and 2014 that meet all environmental discharge requirements for discharge to the natural environment.

1. INTRODUCTION

Various leachate technologies were investigated to treat the leachate generated from the Nyamasoga and Shongweni landfills. The preferred technology was then piloted on-site to prove that the technology can treat the leachate and achieve river discharge standards. This report will explain the technology, describe the pilot trial and then evaluate the chemical analysis of the samples from the operational plant.

1.1. Nyamasoga Landfill

The Nyamasoga Landfill site is a H:H hazardous waste landfill located in Uganda near Lake Albert. The site accepts mostly drilling rig cuttings, mud and effluent. The leachate is collected and then stored in two tanks. The landfill also has a storm water dam at the base of the landfill. The Effluent treatment plant had to be designed so that it could treat the leachate, storm water and incoming effluent to river discharge standards.The volume of leachate and storm water generated by the site is seasonal, thus a plant capable of treating 100 kl/day was proposed to handle the fluctuations. The Nyamasoga leachate has CODs of 10,000 mg/l and TDSs of 21,000 ppm.

1.2. Shongweni Landfill

The Shongweni Landfill is a Class A landfill situated in Kwa-Zulu Natal. The site accepts a mixture of hazardous waste from the surrounding industries. The Landfill is constructed in a valley, so the leachate has a short residence time in the waste body. The leachate is extracted at the base of the landfill and stored in a tank. The leachate is then transferred to 3 large tanks at the top of the landfill. The Shongweni Effluent Treatment Plant needed to be able to treat leachate, storm water and potential effluent streams. The Shongweni leachate has typical CODs of 14,000 mg/l and TDSs of 36,000 ppm.

2. LEACHATE

The reason for having an engineered landfill is to contain waste and prevent it from entering the environment. Modern landfills are designed with a liner system that allows for the collection of leachate and containment of the waste stream.The liner system for a Class A landfill is shown in the diagram below.

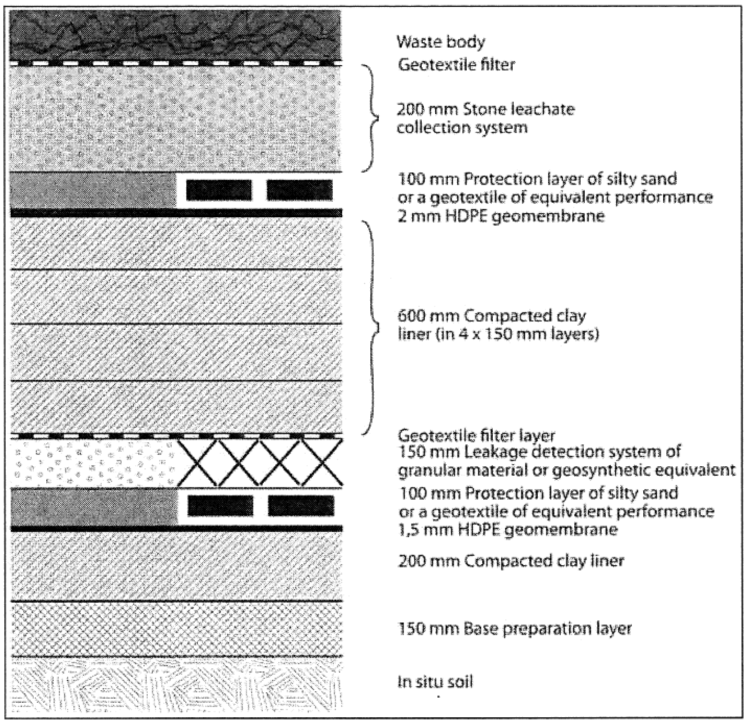

Figure 1: Class A Liner design

There are two ways for liquid to enter into the landfill. One is via the moisture in the waste itself and the second is via rainfall.The liquid migrates through the waste body and picks up contaminants along the way. The decomposition process in a landfill breaks down the putrescible organic waste and the introduction of water acts as a solvent to dissolve digested materials. This water, containing dissolved contaminants is called landfill leachate and eventually reaches the bottom of the landfill cell where it starts to accumulate. If the level of leachate saturating the bottom layer of soil rises, the hydraulic pressure on the liner also increases. This pressure must be relieved to prevent leaks and the leachate is collected via perforated drainage piping.The leachate is then generally stored in dams.

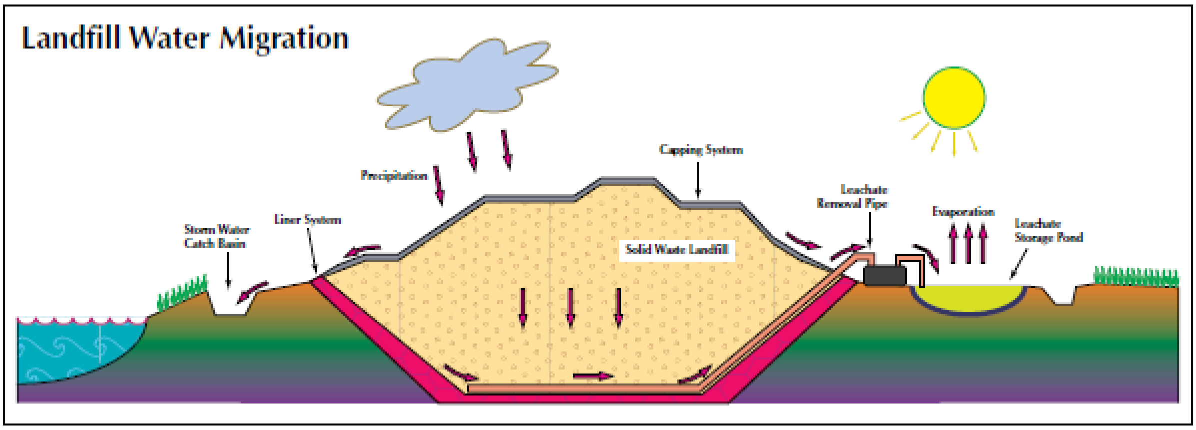

Figure 2: Landfill Water Migration

3. LEACHATE TREATMENT

There are many possible methods to treat landfill leachate. Generally, the technologies can be divided into three groups:

- Conventional
- Biological
- Chemical and physical

3.1. Conventional Methods

3.1.1. Treatment at Sewage Treatment Works

Treatment of the leachate at the municipal effluent (sewage) treatment works is often used to treat leachate from MSW landfills. The leachate is typically blended with the sewage, however,if the percentage leachate is higher than 0.5% by volume, the leachate may affect the operations of the sewage treatment plant and further treatment may be required.This is only an option if the landfill has access to a sewer line and the sewage treatment plant can handle the additional capacity.

3.1.2. Irrigation

Irrigation of land or rehabilitated parts of the landfill can in some cases be utilised. This is obviously dependent on the leachate composition and local legislation. This can mostly be used on capped mature landfills where the leachate is dilute.

3.1.3. Recirculation

Leachate recirculation through the waste body is one of cheapest leachate treatment options. The leachate is collected and then sprayed on the top of the landfill site. A portion of the leachate thus evaporates or gets absorbed by the waste body. Recirculation needs to be monitored as the leachate can affect the stability of the landfill if the volumes of leachate are too large. The leachate also evapo-concentrates, so the leachate composition generally deteriorates with time.

3.2. Biological Methods

3.2.1. Sequencing-batch Reactor (SBR)

A sequencing-batch reactor is a commonly used for the treatment of municipal landfill leachates, but requires further treatment steps. The SBR process is a batch process that is constantly repeated. The leachate is added to the reactor. The reactor is then cycled through an aerobic phase by the addition of air and then an anaerobic phase (oxygen free). These conditions favour nitrification and de-nitrification processes respectively. The organic compounds are degraded and the resultant sludge is allowed to settle. The treated water is then decanted from the reactor. The cycle is then repeated until the desired (treated) leachate quality is achieved.The main disadvantage of the SBR process is that the treated water still requires further treatment for discharge to the environment. The micro-organisms are also very susceptible to chemical contaminants, and thus operation of the plant can be problematic.

3.2.2. Lagooning

Lagooning is the most common form of pre-treatment of leachates. The leachates are stored in lined dams where they can be aerated. This requires a low capital and operational investment. Aeration allows for organic and nutrient removal. The removal of contaminants is achieved by sedimentation and biological decomposition. Lagooning cannot achieve river discharge limits and is merely a pre-treatment and storage solution.

3.2.3. Trickling Filter

A trickling filter is a bed of stones, gravel or plastic material that serves as a support for the growth of micro-organisms. The leachate is sprayed over the top of the bed and allowed to trickle through the bed. The leachate is treated via the micro-organisms in the bed as it trickles through the bed. The sludge generated by the micro-organisms generally clogs the filter with time. Leachates are generally heavily contaminated and thus clog the trickling filter often. The filter then has to be stopped and cleaned. Maintenance of the filter is thus quite high. Trickling filters are thus not often utilised for leachate treatment but are typically used in sewage treatment.

3.2.4.Moving-Bed Biofilm Reactor (MBBR)

An MBBR overcomes the clogging effect of a trickling filter by placing the microorganisms on a plastic material carrier. The carriers are suspended in the leachate and thus the sludge generated during treatment is able to fall through the media to the bottom of the reactor. The suspended carriers are kept in the reactor by sieves. MBBR can achieve up to 90% reduction in nitrogen levels but only 20% in Chemical Oxygen Demand levels. A further treatment step is thus required to reduce the COD.

3.3. Chemical and Physical Methods

3.3.1.Precipitation

Precipitation is the formation of solids via the addition of chemicals. Precipitation is often used to remove Ammonia, Phosphorous and Metals.Ammonia is typically removed by the addition of a Magnesium compound [eg. $Mg(OH)_2$, MgO, $MgCl_2$] and phosphoric acid (H_3PO_4). Phosphorous can be removed by the addition of Aluminium or Iron salts or lime. Metals are generally precipitated out in their hydroxide form by the addition of Sodium Hydroxide or lime.Precipitation is effective for leachate treatment, however, it is quite costly due to the addition of reagents and the generation of a solid sludge that has to be removed and disposed of.

3.3.2.Adsorption

Activated carbon is often used as a polishing step in biological treatment. Activated carbon adsorbs inert COD and some metals. Activated carbon generally is cost prohibitive as the material is expensive and has to be reactivated after use via thermal treatment. The activated carbon can also only be reactivated a few times before requiring replacement.

3.3.3.Oxidation

Aeration is typically used for oxidation, but effective COD removal normally requires stronger oxidation measures. Ozone and peroxide or a combination of the two is often used. The costs of ozone and peroxide are high, and are thus not typically used as a primary treatment step.

3.3.4.Ammonia air-stripping

Intensive aeration of the leachate at high pH (10.5-11.5) in a tower is effective in removing ammonia as a gas from the leachate. The ammonia has to be treated with sulphuric or hydrochloric acid to convert it into the relevant salt (ammonium sulphate or ammonium chloride). Ammonia air-stripping is generally only cost effective at high ammonia concentrations.

3.3.5.Membranes

Membrane treatment is a physical process of filtration. Depending on the membrane pore sizes utilised, the membrane process is defined as: micro-filtration (0.1 micron to 1 micron), ultra-filtration (0.01 micron to 0.1 micron), nano-filtration (1 nm to 10 nm) or reverse osmosis (< 1nm). Reverse Osmosis (RO) was previously not appropriate due to narrow feed channels in the membrane. Now with this limitation removed as in the wide channel flow membrane modules, RO membranes offer an excellent alternative to biological systems. RO membranes are capable of very selective separations and can achieve a filtrate quality better than any biological system. RO membranes are not subject to the loading rate, toxic metals, and temperature limitations of biological systems. Membranes are installed at dozens of landfills worldwide and are becoming more and more accepted as an industry standard.While Reverse Osmosis is a fairly mature technology, the use of it for wastewater treatment is a relatively new advance. The invention of new thin film composite membranes has widened the use of membranes. Thin film membranes can tolerate a broader pH range, higher temperatures, and harsher chemical environments than the previous Cellulose Acetate membranes. RO membranes are used in pressure driven processes and don’t involve energy intensive phase changes or expensive solvents or adsorbents. The RO process is inherently simple to design and operate and in one piece of equipment, simultaneous separation and concentration of both organic and inorganic compounds is possible.

3.3.6.Ion Exchange

Ion Exchange has the potential to remove the ionic species from the effluents/leachates and produce various saleable products. By removing the ionic species, a clean permeate remains which may be utilised on-site or be disposed to sewer. Ion Exchange resins can be used to selectively remove the cations and anions from the leachate/effluent waste stream. A de-ionised water is produced from the system.

3.3.7.Evaporation

Evaporation is the use of thermal energy to evaporate the water portion of the leachate stream to separate it from the contaminants. Evaporation is a very robust technology requiring high capital and operating costs. Evaporation is typically used for complex and highly contaminated effluents.

3.3.8.Freeze Crystallisation

Freeze Crystallisation is specifically designed to treat multi component, high saline waste streams. This is more typical of leachate from hazardous landfills than MSW landfills.Freeze desalination is based on the principle that the structure of an individual ice crystal does not accommodate salts. Therefore, during freezing of a salt solution, salts are rejected by the ice crystals as they form. Impurities are generally more soluble in the liquid phase than in the solid phase, resulting in solute rejection when ice crystals are formed in a salt solution. Freeze desalination processes have the advantage of low operating temperature, which minimises scaling and corrosion. Freeze crystallisation is a relatively new technology with only a few plants operating worldwide. Typically freeze crystallisation is feasible when evaporation is the competing alternative technology as typical physical treatment processes are generally cheaper to install and operate.

4. TECHNOLOGY SELECTION

A summary of the applicable leachate treatment technologies is given below:

Technology	TDS Treatment	COD Treatment	CAPEX	OPEX	River Discharge
Chemical Treatment	X	✓	Low	Medium	X
Biological Treatment	X	✓	Medium	Medium	X
Evaporation	✓	✓	High	High	✓
Freeze Crystallisation	✓	✓	High	Medium	✓
Membranes	✓	✓	Medium	Medium	✓
Ion Exchange	✓	X	High	High	?
Natural Processes	X	✓	Medium	Low	X

Figure 3: Technology Comparison

For the Shongweni and Nyamasoga four possible technology selections appeared feasible:
1. Biological treatment followed by membranes (RO)
2. Evaporation
3. Freeze Crystallisation
4. Membranes (UF + RO)

Evaporation and Freeze crystallisation have high capital requirements and are considered to be economically infeasible due to the size of the Nyamasoga and Shongweni projects. Biological treatment of the leachate is possible but typically operating the plants are problematic and complex due to the varying nature of hazardous waste leachates. The plants are susceptible to poisoning of the biological species used due to chemical contaminants, and constant monitoring of these plants is required.

Membranes have developed significantly in recent years and offer a robust treatment solution. Ultra filtration and reverse osmosis are common technologies with local expertise available. Operators can be quickly trained to operate the plant. These plants are controlled by a Programmable Logic Controller (PLC), with pre-set safety limits. It was thus proposed to pilot the treatment of the leachates with a combination of ultra-filtration and reverse osmosis.

5. PILOT TEST WORK

A pilot plant that consisted of a UF and RO unit was utilised for the trials. Two types of UF membranes and two types of RO membranes were tested. The RO membranes were tested at different pressures and with a second RO pass being part of the trial. A second RO pass is sometimes required to achieve the required river discharge standards.

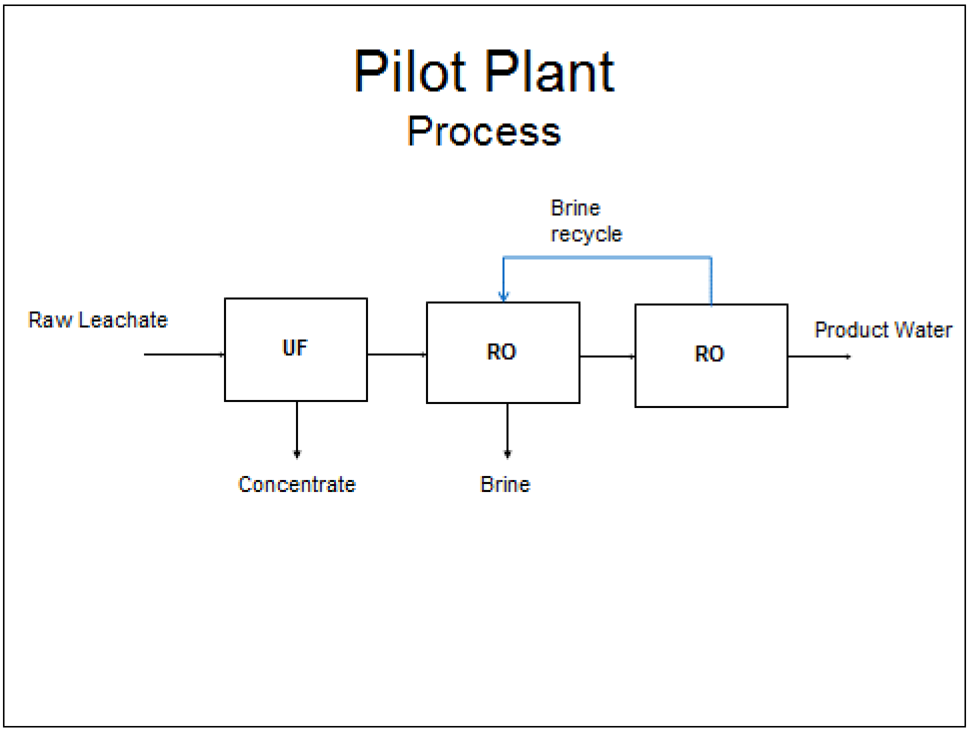

Figure 4: Pilot plant process flow

The schematic diagram (Fig 4) shows the pilot plant process flow. The raw leachate is first passed through a UF membrane and then a RO membrane. The organics are concentrated in the UF treatment step and removed as a UF concentrate. The salts are concentrated in the RO treatment step and are removed as brine. The brine from the second pass of the RO is recycled back to the 1st pass RO.

6. PILOT PLANT RESULTS

6.1. Leachate Analysis

The Shongweni leachate has typical CODs of 14,000 mg/l and TDSs of 36,000 ppm. The Nyamasoga leachate has CODs of 10,000 mg/l and TDSs of 21,000 ppm.

6.2. UF Testwork

Two types of UF membranes were tested. Type 1: A ceramic UF membrane operated in cross flow fashion was selected. Ceramic membranes are robust membranes and can handle a high load of suspended solids and high COD effluent. Type 2: A Polymeric UF membrane operated in dead-end mode with periodic backwash. Both membranes appeared to work efficiently and reduced the suspended solids load. However the ceramic membrane operating in crossflow fashion is able to handle a higher load of suspended solids than the polymeric membrane. The ceramic membrane operated in crossflow fashion achieved a better COD reduction, higher permeate flux rates and higher yields (TSS). The flux rates achieved in the polymeric UF membrane were low and proved to be economically infeasible, as the membrane has to be back-flushed often to maintain flux.

6.3. RO Test work

Two types of RO membranes were tested; a salt water membrane and a brackish water membrane. The membranes were tested at different operating pressures. An initial pressure is required to overcome the osmotic pressure of the salt present in the water. The higher the pressure the cleaner the RO permeate should be. From the data the Salt Water RO membranes appear to work more efficiently as they show the larger reduction in electrical conductivity.

6.4. RO 2nd Pass Test work

The permeate from the first pass of the RO membrane was run through the same membrane again. A second pass of the membrane removes further contaminants and a cleaner permeate is obtained. A second pass of the RO membrane is typically required when the permeate is required to meet river discharge standards.

7. OPERATIONAL PLANT DESIGN

From the test work performed, it was proposed that a leachate plant for treating the Nyamasoga leachate with the following specifications was required:
1. pH correction and solids precipitation
2. Ceramic Ultrafiltration Plant
3. Single Pass Reverse Osmosis

From the test work performed, it was proposed that a leachate plant for treating the Shongweni leachate with the following specifications was required:
1. Ceramic Ultrafiltration Plant
2. pH correction
3. Double Pass Reverse Osmosis
8. Operational Plant Results

Figure 5 and 6 illustrate the operational analysis from the Nyamasoga and Shongweni Leachate Plants.

Parameter	**Units**	**Feed**	**Galaxy Permeate**	**UF Permeate**	**RO Permeate**	**National Effluent Standards**
pH		10.05	9.96	9.95	7.47	6 - 8
Conductivity	**mS/cm**	23.2	22.7	22.7	0.347	1.8
TDS	**mg/l**	48 730	44 428	30 879	58	1 200
TOC	**mg/l**	71 233	69 260	56 033	-	
Alkalinity	**mg/l**	0.627	0.596	0.485	0.543	500

Figure 5: Nyamasoga Plant Results

The Nyamasoga Plant was expected to receive acidic waste streams, however the client decided to neutralise the effluent themselves and thus the feed to the plant is alkaline. The feed has a high TDS and TOC. The UF is an effective pre-treatment for the RO module and reduces the suspended solids as well as TOC. The RO is very effective in removing the TDS with efficiencies of approximately 99%. The RO treats the combination of leachate, effluent and storm water to river discharge standards.

Parameter	Units	Feed	UF Permeate	RO Permeate	National Effluent Standards
pH		8.2	8.9	7.5	6 - 8
Conductivity	mS/cm	54.7	9.52	0.19	1.5
TDS	mg/l	36030	4298	70	975
COD	mg/l	12784	571	16	75
Ammonia	mg/l	161	107	0.15	6
Sulphide	mg/l	32	<0.04	<0.04	

Figure 6: Shongweni Plant Results

The feed to the Shongweni plant is a combination of leachate and storm water. The feed has a high TDS and COD loading. The Feed is pre-treated with Hydrogen Peroxide to reduce the COD load to the plant. The UF is effective in removing the suspended solids and reducing the COD. The double pass RO is very efficient in removing the TDS and remaining COD to achieve the required river discharge standards.

The ammonia and sulphide levels in the feed do occasionally cause challenges on the plant. pH reduction before the RO was attempted to reduce the ammonia but resulted in Hydrogen Sulphide odours. The current process thus treats the effluent at the incoming pH. If there is any residual ammonia or sulphide it is treated with Hydrogen Peroxide to achieve the river discharge standards.

9. CONCLUSION

A desktop literature survey was performed on leachate treatment technologies. A combination of ultra-filtration and reverse osmosis was selected as the best balance between economic and technically feasible solution for piloting. A pilot plant was hired, and a various tests were conducted on the leachate. Two UF membranes; a ceramic and polymeric membrane were tested. Two RO membranes (a salt water membrane and a brackish water membrane) were tested at various pressures.

The pilot plant test work showed that the landfill leachate could be successfully treated by a combination UF and RO membrane plant.

A ceramic ultra-filtration and reverse osmosis plant was constructed and commissioned at the Nyamasoga and Shongweni landfill sites. Both plants are successfully treating the incoming feed to their respective river discharge standards.

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