THE DURBAN/WORLD BANK LANDFILL GAS TO ELECTRICITY CDM PROJECT – BEHIND THE SCENES AT MARIANNHILL AND LA MERCY

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ABSTRACT

The Durban/World Bank Landfill Gas to Electricity CDM Project was finally underway in February 2006, after many years of project development by Durban Solid Waste (DSW). Landfill gas extraction systems were first installed at the Mariannhill and La Mercy Landfills, and the commissioning of these systems was completed in November 2006. Reciprocating gas engines and electricity generation systems were installed and commissioned in December 2006. The successful implementation of these electricity generation schemes, the first of their kind on the African Continent, has provided the eThekwini Municipality with a total electrical generation capacity of 1,5 MW.

The successful implementation of the project necessitated the resolution of many technical and construction related problems, most of which were unique to each site. The technical differences between the two sites, only 40km apart, were vast to say the least. The influence of properly engineered lining systems, waste compaction, rainfall and capping systems cannot be underestimated in terms of their influence on the design and implementation of a landfill gas extraction system, as illustrated by the experience gained on this project.

The key features of the project included the following:

- The installation of vertical gas recovery wells and gas collection pipework at two sites within the eThekwini Metropolitan area
- The installation and commissioning of gas delivery units, comprising variable speed blowers and high-temperature gas flares
- The installation and commissioning of containerized reciprocating gas engines and electricity generation units
- The installation and commissioning of step-up transformers and electrical switchgear, feeding into the municipal grid

This paper addresses the key features of the project, specifically relating to technical issues and the unique site conditions and problems encountered.

KEYWORDS

CDM, landfill gas extraction, reciprocating gas engines, electricity generation, gas recovery wells, gas delivery units, variable speed blowers, high-temperature gas flares

INTRODUCTION

Following years of project development, in 2004, the eThekwini Municipality signed an agreement in Cologne, Germany, for the purchase of emission reduction credits by the World Bank's Prototype Carbon Fund. The agreement was based on the destruction of methane, a greenhouse gas with a potency of 21 times that of carbon dioxide, generated through the decomposition of landfilled organic waste at the muncipality's Mariannhill and La Mercy landfill sites, and the generation of electricity. This was the first Clean Development Mechanism (CDM) project in Africa, provided for through the Kyoto Protocol, based on the sustainable use of landfill gas (LFG).

Following a protracted EIA process, the contracts for the landfill gas extraction and electricity generation systems were finally awarded in January 2006. The commissioning of the landfill gas extraction systems was completed in November 2006, and the reciprocating gas engines and electricity generation systems were installed and commissioned in December 2006. The successful implementation of these electricity generation schemes has provided the eThekwini Municipality with a total electrical generation capacity of 1,5 MW.

Many technical and construction related problems, most of which were unique to each site, were encountered, particularly during the gas extraction contract. The technical differences between the two sites, only 40km apart, were vast. The influence of properly engineered lining systems, waste compaction, waste composition, rainfall and capping systems all played a major role during construction, and even now, during the operation of the plants.

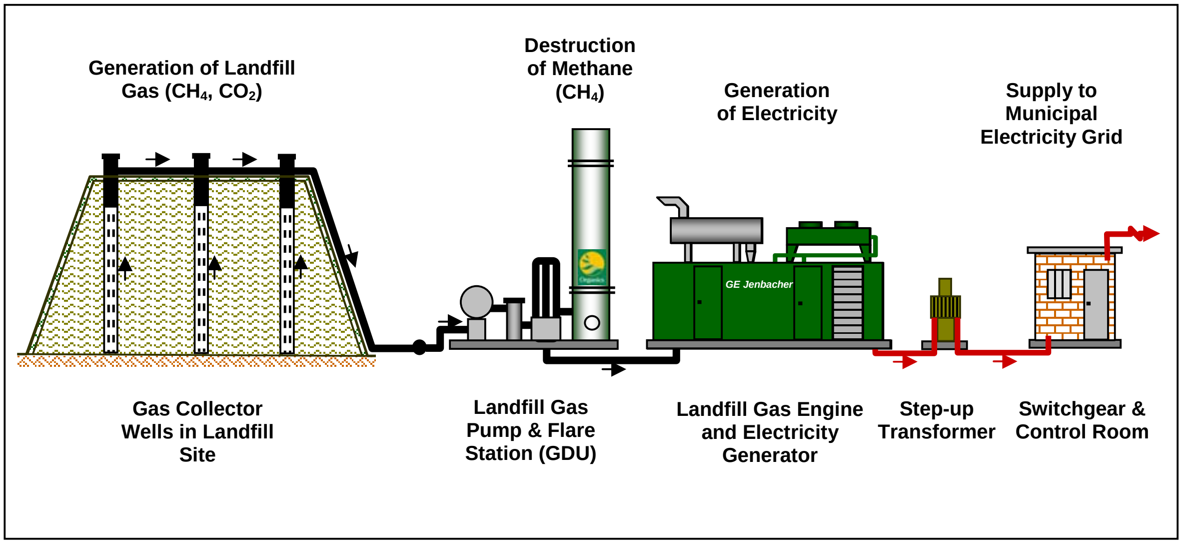
THE LANDFILL GAS EXTRACTION AND ELECTRICITY GENERATION SYSTEMS

Essentially, the LFG extraction systems at both sites comprise a series of vertical gas wells, connected by gas collection pipework leading to a Gas Delivery Unit (GDU) with a variable speed blower and high-temperature flare. The GDU's also include various gas filters, a condensate knock-out chamber and shut-off valves. The vertical gas wells were constructed using the auger drilling technique, followed by the insertion of perforated HDPE recovery pipes surrounded by a stone packing. The gas wells were completed with the installation of pre-fabricated HDPE wellheads which allow for the regulation of gas flow from any particular gas well, and a hydrated bentonite seal to prevent the ingress of air under extraction conditions of negative pressure. Each wellhead was then connected to the HDPE gas collection pipework laid to falls to enable the efficient drainage of condensate forming in the pipes. At low points in the collection pipework, condensate drainage systems were installed, facilitating the delivery of relatively dry LFG to the generation compound.

The blowers on the GDUs, designed and manufactured by Organics (UK), are used to extract the LFG from the landfill under low negative pressures, typically ranging from -10mb to -60mb. The ground enclosed flares have a design capacity of 1000 Nm^3/h with a turn down ratio of 5:1. Proper control of the extraction pressure and wellhead valves typically should result in the delivery of LFG at a fairly constant flow rate, with a methane content of between 40% and 45%, a similar carbon dioxide content, and an oxygen content of less than 3%. Balance gas or Nitrogen levels are also monitored, since excess levels of nitrogen would indicate that air is being pulled into the waste, even if the measured oxygen levels are low. This is normally due to the consumption of oxygen through aerobic decomposition or a subsurface fire. The ultimate consequence of excessive air ingress would be the destruction of the methane producing anaerobic bacteria, and hence would affect the process of LFG production.

The LFG delivered to the GDU is then either fed to the flare or to the gas engine, resulting in the combustion of the gas at all times, even during engine shut-down conditions. The gas engines, manufactured by GE Jenbacher (Austria), are specifically designed for LFG operation and are fitted with gas pressure sensors which regulate the power output of the generators, with a turn-down capacity of 50%. This enables the engines to adjust to varying conditions of gas flow and gas quality which occur on a daily basis, as opposed to constantly demanding a particular flow of a particular quality to achieve a set power output. The generated low-voltage power is fed to a step-up transformer which feeds 11kV switchgear, providing protection and connection to the municipal network. A schematic diagram of the extraction and generation scheme is provided in Figure 1 below.

Figure 1: Schematic layout of landfill gas to electricity scheme



THE MARIANNHILL LANDFILL SITE – CONSTRUCTION & OPERATION

Drilling and construction of the gas wells

In addition to six existing vertical baseline gas wells, located in cells 1 & 2, one new vertical well was constructed in cell 2, and six new vertical wells were constructed in cell 3, providing a total of 13 vertical gas wells for extraction. Well depths ranged from 8m to 18m, averaging roughly 15m. In addition to the vertical gas wells, 9 riser pipes, originally constructed as part of the basal lining system of cell 4, were connected to the collection pipe network. Recently, in June 2007, 4 additional vertical gas wells were installed in cell 4, ranging from 14m to 20m in depth.

Initially, a 400mm diameter augur was used for the drilling, but this had to be increased to 500mm to enable the efficient installation of the wellheads which had to be fitted over the top end of the recovery pipe. The presence of rubber materials, wooden products and tyres severely hindered progress with the narrower augur, and effectively reduced the final diameter of the drilled wells. In cell 4, a 600mm diameter augur was used successfully after initially experiencing problems with tyres and large pieces of timber. At times, gas well collapse was experienced during drilling, where the sides of the well collapsed at various depths during or after the removal of the auger. This provided an indication of the importance of waste compaction during landfilling.

Generally, the installation of the gas wells at Mariannhill proceeded smoothly and successfully. A few of the wells had to be abandoned due to augur refusal occurring before the specified depths were reached, resulting in re-location of the affected gas well positions. Occasionally, perched leachate was intersected during drilling which initially drained and collected at the bottom of the drilled wells. This drained out of the gas wells over a period of a few days, indicating that the drainage of leachate from the waste body was generally efficient. At Mariannhill, leachate produced by the landfill is managed through the use of a leachate drainage system incorporated in the design of the liner and a leachate treatment plant. Initially, the project design included a leachate pumping system for the removal of accumulated leachate in the gas wells, but this was deemed unnecessary after evaluating the status of the newly drilled gas wells.

For the sealing of the wellheads, the project design only allowed for a 400mm deep hydrated bentonite seal, placed and tamped around the wellhead in the drilled annulus. This was constructed and appears to have been reasonably successful to date.

The gas collection pipework

A total of some 2300m of HDPE gas collection pipework was laid, ranging in size from 90mm to 250mm in diameter. The six original baseline wells were connected in a ring, feeding into the main gas collector line, with a thermal mass flowmeter to measure the collective baseline flow separately from the “project” flow from the new gas wells. The new wells on cells 2 and 3 were connected to the main collector line with a maximum of 3 wells on a branch. The 9 riser pipes were all connected in series to a “ring” collector line with an isolation valve and monitoring point which in turn joined the main collector line downstream. This has since been altered, with 5 of the risers remaining on the original line and the remaining 4 connected to a new ring collector line. The 4 new vertical wells in cell 4 were connected to a separate ring collector line with an isolation valve and monitoring point.

At various low points, condensate knock-out chambers were installed. These had to be of the barometric leg type, comprising two separate chambers separated by sufficient elevation down a physical slope of embankment, due to a restriction on the depth that could be utilised. In one area, the knock-out was located on the edge of the site where the liner was located near the surface, and in another, adjacent to the generation compound, hard and rocky conditions were experienced.

The collection pipework layout had to be carefully considered to allow for sufficient falls to accommodate condensate drainage, in addition to having to connect directly to the through-flow wellheads that had been specified. The use of through-flow wellheads meant that the final position of the gas wells dictated the final layout of the collection pipe network. The 4 new wells in cell 4 were constructed differently, utilizing a “ring-main” where each gas well connects to the ring-main via a flexible pipe. In this way, the collection pipe trenching and installation could proceed independently from the gas well auguring and installation, thereby saving time.

The generation compound

At Mariannhill, the generation compound is located at a reasonable distance from the landfill, on the opposite side of the main access road to the site, up on the side of a hill. This has effectively negated the usual problems of LFG migration normally associated with buildings and plants on or near a landfill. The gas enters the fenced compound via the main gas collection line which is connected to the gas inlet on the GDU.

The generation compound is located on a particularly hard, rocky area, which resulted in some difficult excavation during construction of the concrete bases and control building. In particular, the installation of the electrical copper earth mat material was complicated by the fact that the copper had to be laid in relatively shallow trenches and the earth spikes had to be drilled into rock. On the other hand, the stable subsurface conditions lent themselves to the layerworks and foundation design and construction. Surface drainage was also simplified due to the elevated position of the generation compound.

Gas field monitoring and adjustments – the status quo

The GDU was commissioned in November 2006. Initially the total extraction rate was of the order of 250 Nm^3/h, prior to bringing the riser pipes on-line. The flow increased to the order of 570 Nm^3/h when the riser pipes were brought on-line, indicating the significance of the contribution of the risers to the total flow. These flows were achieved at an extraction pressure of -15mb, and yielded a gas quality of 45% to 50% methane and less than 2% oxygen. The contribution of the original baseline wells was of the order of 50 Nm^3/h.

During initial operation of the plant, gas quality monitoring was undertaken at each well. Based on the results, the gas valves were adjusted to regulate the suction pressure applied at the wellheads. During the monitoring, it became evident that pressure losses along the main collector line connecting the nine risers resulted in inefficient LFG recovery from the last four risers, with little or no extraction pressure being measured. This resulted in the recent splitting of the riser pipes into two sections with separate collector mains. In addition, some of the gas wells located near the side slope of the landfill have had to be turned down to limit the ingress of oxygen.

Seasonal climatic variations have also had a significant effect on LFG extraction. Now, in the winter season, drier and cooler conditions have resulted in a decrease in overall gas recovery from the landfill. Currently, the total extraction rate (following the installation of the four new gas wells in cell 4) is of the order of 450 Nm^3/h with a gas quality of approximately 45% methane and less than 2% oxygen, with the quality being fairly sensitive to even slight variations in extraction pressure. Power output measured at the generator is of the order of 800 to 850 kW. This is expected to increase to around the generation capacity of 1 MW during the wetter, warmer months to come in the summer.

THE LA MERCY LANDFILL SITE – CONSTRUCTION & OPERATION

Drilling and construction of the gas wells

At La Mercy, the site was divided between the northern section and southern section, with the two separated by an old access road. Six wells were installed on the southern section and eight were installed in the northern section. On the southern section, well depths were generally about 9m deep, with one of 18m. On the northern section, the well depths ranged from 8m to 16m, averaging approximately 12m.

In February 2007, one of the gas wells in the southern section was abandoned due to very high oxygen levels indicating the ingress of air through the side slope of the landfill, and this was replaced with a new gas well moved further away from the edge. Three additional gas wells of

14m in depth were also installed in the northern section, in between the original wells, in an effort to increase the rate of gas extraction.

Using the experience gained at Mariannhill, a 500mm diameter augur was used for the drilling. This proved to be very effective, and at the time of drilling the original gas wells, the drilling supervisor commented on the ease with which the augur was proceeding and the relative “neatness” of the holes compared to Mariannhill. This was most probably due to the presence of a significant quantity of fine soil cover material in the waste column that had been used during landfilling, which helped to stabilise the waste during drilling.

For the sealing of the wellheads, as for Mariannhill, the project design only allowed for a 400mm deep hydrated bentonite seal, placed and tamped around the wellhead in the drilled annulus. This was generally unsuccessful and is discussed in further detail below.

The gas collection pipework

A total of some 900m of HDPE gas collection pipework was laid, ranging in size from 90mm to 250mm in diameter. The wells were connected in lines of three which would then tee onto a main header line on both the south and north sections of the site. Each of the two header lines were fitted with an isolation valve at the point of confluence, and a single gas main was installed to carry the collective gas to the generation compound.

A condensate pumped sump was installed in the generation compound, prior to the main gas line entry to the GDU. This was necessary as the compound was located at the foot of the eastern side slop of the landfill and condensate collecting at this low point had to be removed with an automated submersible pump system. No other condensate removal points had to be installed, as all the gas lines fell away from the direction of gas flow and condensate would drain into the respective gas wells along the collection lines. As a result, it was especially important to carefully consider the collection pipework layout to allow for sufficient falls to accommodate efficient condensate drainage. As with Mariannhill, the use of through-flow wellheads meant that the final position of the gas wells dictated the final layout of the collection pipe network. Many difficulties were experienced during the trenching operation due to heavy rainfall in the latter months of 2006.

The generation compound

At La Mercy, the generation compound is located at the foot of the eastern side slope of the northern cell of the landfill. An access road runs in between the fenced compound and the site, and as a result, the main gas delivery line had to be trenched from the landfill into the compound under the road surface. This has unfortunately created a conduit for LFG migration to the compound area, especially as the compound is at a relatively low point. As LFG is denser than air, it has been detected in small quantities in the control room cable trenches and the pumped sump access chamber. Attempts have been made to stop LFG migration through the installation of a bentonite seal around the gas line, but this has not been very successful.

The generation compound is located in a fairly soft soil area (Berea Red soils), which assisted with the installation of the sub-surface works, including the electrical copper earth mat. However, foundations for the heavy equipment, such as the gas engine, had to be upsized.

Leachate management

The first major problem at La Mercy arose during the initial drilling and gas well installation. Significant quantities of leachate were encountered, and following the drilling, this leachate was expected to drain out the bottom of the gas wells. Unfortunately, this was not the case, and following the installation of the perforated recovery pipes and wellheads, some of the wellheads literally "floated" out of the gas wells, due to both the presence of leachate and LFG bubbling though the leachate. Static leachate levels were measured, and in some of the gas wells, the initial static leachate level was measured at less than two metres below the top of the wellhead. The gas wells in the northern section proved to be particularly problematic in terms of the presence of leachate. The gas wells located close to the edge of the landfill were generally drier than the others. Refer to Table 1 below which provides monitoring data as recorded by an independent party.

Based on these findings, it was decided to install the leachate extraction system that had originally been envisaged for the Mariannhill site. This included the installation of an air compressor, pneumatic lines and leachate extraction pumps to the individual gas wells. Leachate discharge lines also had to be installed. Initially, the contract only envisaged the supply of four pumps. Additional pumps were however required, and at present, twelve pumps are in operation, with only five wells in the southern section not requiring leachate removal. Although these pumps are being used to effectively remove leachate from the wells, approximately two to three metres of well depth is lost at every well, due to the length and operating requirements for these pumps. A total leachate volume of the order of 30,000 to 40,000 litres is currently being pumped out of the gas wells per week. This flow rate has not realistically reduced since commissioning the pumps, which is also of concern due to the fact that most of the pumping has taken place during the dry season.

Table 1: La Mercy Gas Well Monitoring Data – Leachate Levels

Gas Well	Actual Well Depth (m)	Leachate Levels December 2006 (m)	Leachate Levels January 2007 (m)	Leachate Levels March 2007 (m)
1	10.15	5.33	6.2	6.18
2	8.45	1.90	6.24	6.2
3	18.60	5.05	1.65	6.8
4	n/a	6.77	6.75	abandoned
5	12.6	11.50	11.3	11.1
6	11.00	9.38	9.49	9.8
7	8.28	1.93	2.80	***2.37***
8	7.90	3.12	5.15	***4.75***
9	12.40	6.90	8.0	***4.64***
10	10.70	5.60	4.55	***4.2***
11	14.25	Dry	11	10.6
12	15.3	Dry	11.2	9.73
13	9.8	2.3	4.8	***2.5***
14	14.00	0.93	2.9	***2.4***
15 (new)	14.00	N/a	N/a	***4.1***
16 (new)	14.00	N/a	N/a	***5.3***
17 (new)	14.00	N/a	N/a	***3.4***
18 (new)	14.00	N/a	N/a	12.83

Note: *All depths were measured from the top of wellhead*
Bold text = wells with < 6m "aerated" zone

In addition to the problem posed by the presence of such large quantities of leachate, it would appear that the drainage properties of the compacted waste body pose a different problem. The leachate extraction pumps are more than capable of pumping large volumes of leachate out of the gas wells, but the rate of leachate ingress to the wells has been proven to be fairly low. For the leachate to be effectively removed, it first has to drain into the gas wells, and this appears to be taking a very long time. As the hydrostatic curve is drawn down in the vicinity of the gas wells, the leachate takes even longer to reach the gas wells, a situation exacerbated by the non-homogeneous nature of the landfilled solid waste and the tendency for perched leachate layers to form at different levels in the waste body.

Gas well silting

When the gas wells were dipped to determine leachate levels, it also became apparent that significant silting of the perforated recovery pipes was taking place. This phenomenon appeared to occur randomly in terms of the specific locations of the affected gas wells. While some gas wells exhibited very little silting, others exhibited silt depths in excess of 2 or 3 metres, with the worst at around 7 metres. This would have limited the depth to which the leachate extraction pumps could be installed, and the wells were therefore purged or de-silted using a pneumatic venturi technique prior to pump installation. Even so, silting continued, and in some cases the leachate pumps became blocked and the wells had to be re-purged. This process has been carried out three times on all wells and four times on some others as shown in Table 2 below.

The most logical explanation for the silting phenomenon is that a significant quantity of fine sand material (Berea Red) was used as daily cover during landfilling operations. As the vast quantities of leachate entered the gas wells during construction and continued upon commencement of leachate extraction from the wells, large quantities of this fine material were hydraulically transported towards the gas wells and into the recovery pipes. It has been observed that gas well silting has reduced after the second or third purging operation, but it is suspected that although the material in the recovery pipes has been removed, a significant quantity of the fine material is now clogging or blinding the stone pack around the recovery pipes, and beyond, resulting in a less permeable area in the immediate vicinity of the gas wells. This further reduces the flow of leachate to the wells and critically reduces the flow of LFG to the wells under a given extraction pressure. As a result, extraction pressures have to be increased to maintain a stable flow of LFG. A possible solution to this problem could be to repeatedly flush the affected gas wells with water in an attempt to move the silt from the surrounding area into the recovery pipes to facilitate its removal.

Gas well sealing

As extraction pressures are increased to maintain a reasonable flow rate, mainly due to the effects of leachate and silting on the drainage properties of the waste body, greater strain is placed on the gas well seal. As for Mariannhill, the project design allowed for a 400mm deep hydrated bentonite seal, placed and tamped around the wellhead in the drilled annulus. Following commissioning of the plant, it was quickly determined that this was insufficient, as seal leaks were detected throughout the wellfield during gas quality monitoring at the individual wellheads. The degree of air ingress was significant under these circumstances. Contributing to this was the fact that the landfill capping was generally fairly impermeable, preventing the ingress of air through the upper layers of the landfill. Effectively, this meant that the high extraction pressures were applied to a very small sphere of influence around each gas well, and something had to fail to relieve the pressure.

Table 2: La Mercy Gas Well Monitoring Data – Well Depth Records

Gas Well No.	Depth Before Purging Dec 2006 (m)	Depth After Purging Dec 2006 (m)	Measured Depth January 2007 (m)	Depth of Sediment January 2007 (m)	Depth before Purging March 2007 (m)	Depth after Purging March 2007 (m)	Depth of Sediment March 2007 (m)
1	10.15	10.15 (Not Purged)	10.12	0.03	10	10.15	0.15
2	3.70	8.45	8.40	0.05	8.4	8.45	0.05
3	6.60	18.60	18.60	0	18.5	18.60	0.10
4	8.75	8.75 (Not Purged)	7.60	**1.15**	abandoned	N/a	N/a
5	12.6	12.6 (Not purged)	12.40	0.20	12.4	12.6	0.20
6	10.93	11.00	10.94	0.06	10.9	11.00	0.10
7	6.65	8.28	8.25	0.03	8.05	8.28	0.23
8	4.85	7.90	7.05	**0.85**	6.8	7.90	**1.10**
9	6.90	12.4	12.2	0.20	11.8	12.40	**0.60**
10	7.20	10.70	7.70	**3.00**	7.25	10.70	**3.50**
11	13.1	14.25	13.25	**1.00**	13.3	14.25	**0.95**
12	14.4	15.3	13.25	**2.05**	14.3	15.3	**1.00**
13	8.50	9.8	9.1	**0.70**	9.4	9.8	0.40
14	4.50	5.75 (blocked?)	4.8	**0.95**	9.8 (Re-drilled)	14.00	**4.20**
15 (new)					13.8	14.00	0.20
16 (new)					11.6	14.00	**2.40**
17 (new)					6.75	14.00	**7.25**
18 (new)					14.00	14.00	0

Note: All depths measured from collar of collector wellhead
Bold text = sedimentation > 0.5m

The design for the sealing detail was revised, allowing for a 1m deep hydrated bentonite seal, a 1,5m wide, 250 micron plastic (HDPE) skirt clamped to the body of the wellheads, a compacted G5 soil layer and a cement stabilized sand layer. Again, this failed under extraction conditions. Following this, all the gas well seals were reinstated using a simplified third design. This allowed for a 1,5 to 2m deep cement stabilized hydrated bentonite seal, and a 5m wide plastic skirt clamped and taped to the body of the wellheads, overlaid with another layer of bentonite within the wellhead access chamber. This appears to have been relatively successful, but as LFG flow rates have recently decreased and extraction pressures have been increased, this may not continue to be the case.

A critical issue identified during the re-sealing process was that of gas well venting. It became apparent that gas well venting during periods of down-time is important in preserving the status of a gas well seal, especially in a site where the drainage properties of the waste body do not readily allow for the dissipation of residual LFG pressures away from the gas well conduit. At La Mercy, residual pressures in the gas wells continue to be significant during periods of down-time and these pressures have to be released by venting to prevent compromising the gas well seals.

Gas field monitoring and adjustments – the status quo

As for Mariannhill, the GDU was commissioned in November 2006. Initially, the total gas extraction rate was of the order of 180 Nm^3/h. These flows were achieved at an extraction pressure of -40mb, and yielded a gas quality of approximately 45% methane and 3% to 4% oxygen. Over a period of less than two weeks, the total flow reduced to approximately 140 Nm^3/h, with methane levels of 40% and oxygen levels rising to above 4%. The higher initial flows and gas quality could be attributed to the presence of residual gas within the waste body, which rapidly became depleted through extraction.

As the residual gas became depleted and problems related to leachate extraction and gas well silting became manifest, methane levels started to fall and oxygen levels started to rise substantially. The gas wells located near the edge of the landfill also contributed to this problem due to the apparent tendency to draw air into the landfill through the side-slopes. As discussed above, on a few occasions, the wellfield was turned off for short periods to allow for the reinstatement of wellhead seals. Again, as extraction commenced, gas flow and quality appeared to be respectable, but rapidly deteriorated as stable flow conditions were attained.

At present, the total stable extraction rate is only of the order of 80 Nm^3/h at an extraction pressure of -60mb. Gas quality is currently approximately 41% methane and 5% oxygen, indicating that further action must be taken to improve gas quality, either by reducing extraction pressures, closing certain gas wells, or by repairing gas well seals that may have been compromised. A flow requirement of approximately 190 Nm^3/h with an oxygen content of less than 3% to run the electrical generation plant, at the minimum generation capacity of 50% or 250 kW is an objective that currently appears to be unattainable, especially due to the fact that 11 of the 17 operational gas wells have had to be completely turned down already.

CONCLUSIONS

A number of conclusions can be drawn from the experience gained thus far during the implementation of the eThekwini landfill gas to electricity CDM project.

1. A detailed site investigation and pumping trial to prove the sustainable gas well extraction rate from any particular landfill is critical. Such an investigation would typically cost a few hundred thousand rand and should be seen as an investment rather than a cost. Such an investigation would enable the project developer to accurately ascertain the number and spacing of gas wells required and would ultimately assist in determining the financial feasibility of the project. A desk study and a detailed gas generation assessment model is important, but this needs to be verified in practice, especially where assumptions often have to be made during the modeling process where accurate waste and site data does not exist. At the La Mercy landfill, it would appear that the volume of leachate in the site and the quantity and type of soil cover material used during landfilling has had a significant influence on the drainage properties of the waste body, resulting in the low extraction rates achieved thus far. This was not envisaged prior to construction.

2. The spacing and layout of gas wells should be carefully considered, based on site specific knowledge and pumping trial results. To design a gas well layout with a nominal spacing of 50m centres, based on the industry rule-of-thumb, is simply not good enough when one considers the cost of gas well installation (of the order of R 100 000-00 per

gas well). Site specific conditions will dictate the extraction sphere of influence of each particular gas well, and this will directly determine the extraction efficiency of the overall system as compared to the expected gas generation rates predicted through the initial modeling process. Influencing factors include the type of lining system (if any), allowances for leachate drainage, the type and quantity of daily cover material used during landfilling, the degree of waste compaction attained, and the nature of the surface or cover of the landfill including surface drainage design. Gas wells should also, preferably, not be positioned near the edges of a landfill.

3. Wellhead seals need to be properly designed and constructed, in order to prevent the ingress of air during extraction conditions. The most likely point of ingress will be at the physical wellhead/seal interface, where a leak will either be propagated by the gas under residual positive pressure, or by exceeding a certain negative pressure during extraction. At Mariannhill, a simple 500mm deep hydrated bentonite seal proved to be effective, whereas at La Mercy, difficulties have still been experienced with an improved seal incorporating a cement stabilized bentonite seal and a 5m wide plastic skirt, tightly taped to the wellhead body. Seals will become compromised at the point where residual pressure within the well cannot dissipate within the waste body of the landfill, or the waste body simply cannot produce a reasonable flow of gas under extraction conditions. In this case, the higher the suction pressure, the greater the likelihood of a leak, either through the seal or through the surrounding surface layers of the landfill capping material. In addition, during periods of down-time, gas wells should be vented at the wellheads to prevent compromising the gas well seals as a result of the build up of residual gas pressures within the wells.

4. The design of the gas collection pipework layout must be carefully considered. International experience has shown that no more than 3 or 4 gas wells should be connected to any particular branch line, with more than this resulting in inefficient extraction rates. This was illustrated by the gas quality and pressure readings taken on the 9 gas riser lines at Mariannhill. In addition, each branch off the main collector line should be equipped with an isolation valve and monitoring point to enable the collective sampling of gas extracted from all the gas wells located upstream of that point.

5. The design, construction and operation of a landfill must take cognisance of typical gas extraction requirements where a LFG extraction project is envisaged. This includes the physical sizing of landfill cells to provide a sufficiently large area for an effective sphere of influence of the envisaged gas wells, the installation of a lining system incorporating a leachate drainage system (where leachate production is expected), and the proper selection and minimal application of daily cover material. In addition, the landfill capping design needs to be carefully considered, allowing for a surface of relatively low permeability which facilitates the drainage of excess surface water.

6. The location of an extraction and generation compound must be carefully considered so as to avoid the possibility of LFG migration from the site becoming a problem. The area should preferably be located on high ground, if possible, which also assists in draining condensate away from the gas inlet to the GDU.

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