Beyond the Well – The Landfill Gas to Electricity CDM

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ABSTRACT

The Durban Landfill Gas to Electricity Clean Development Mechanism (CDM) project has been Africa's first Landfill CDM Project. It has contributed to the Metro's electricity supply and received revenue from methane (CH_4) destruction in the form of Certified Emission Reductions (CER's) and electricity sales. Preliminary findings from research undertaken by the Department of Cleansing and Solid Waste, (DSW), favoured the installation of horizontal gas extraction wells (HGW) due to simpler construction, relatively lower costs, compatibility with landfill operations and access to the landfill gas (LFG) soon after waste placement as opposed to vertical gas extraction wells (VGW), (Moodley et al, 2010). This paper is a continuation of the research on LFG extraction improvement and optimisation with particular focus on evaluating the life expectancy of typical LFG extraction wells through the experience gained in the management of the gas field. Innovation design aspects and upgrades are discussed to demonstrate the extraction enhancement as well as practical construction challenges. The projects overall improvements are also discussed relative to cost benefits in terms of reduced engine/extraction system maintenance. In addition, the current poor performance of the CDM market has necessitated DSW to investigate alternative opportunities in utilising LFG as a resource and future developments are highlighted.

1. INTRODUCTION

Methane (CH_4) is the second most concerning greenhouse gas (GHG) after carbon dioxide (CO_2) and is confirmed to have a global warming potential of 21~25 times that of CO_2. The production of CH_4 within a landfill waste body is simply formed by methanogenic microorganisms under anaerobic conditions and is typically 50~60% by volume. As a result climate change emanating from GHG's is resulting in negative environmental impacts globally. Whilst it is understood that GHG's can be reduced if there is strict adherence to the waste hierarchy with prevention being most desired and disposal being least desired, one can argue, at this stage, whether South Africa can practically realise such an order. Landfilling is seen as the most cost effective safe environmental option at this stage and this continues to add to climate change for the foreseeable future. Therefore the implementation of an active LFG extraction system is proven to be a mitigation measure to reduce environmental impacts.

The eThekwini municipality's landfill gas to electricity project has been Africa's first registered CDM project dating back to early 2000. However, LFG extraction on the Durban landfills dates back earlier even before the CDM process where LFG management was undertaken as best practice to combat potential offsite migration and treatment from a health and safety perspective. An example is the Bisasar Road Landfills curtain well protection system that was installed to cut off LFG migration and subsequent flaring as far back as the mid 1990's. The illustration of this point shows that LFG extraction is not new and been in the local landfilling industry for some two decades with international experiences since the mid 1960's to early 1970's, (Darrin, 2005).

Previous investigations by the department showed that the pioneering gas extraction technique is undoubtedly the vertical gas well (VGW) and due to its common use in the landfill industry, its design and performance was always accepted but not questioned (Moodley, 2010). Since the VGW can predominately only be installed at final design levels of cells on landfills and coupled with the fact that Durban is sited in a sub-tropical climate, results in significant quantities of LFG being produced early in the life of the landfill with a relatively high CH_4 content. This effectively renders the VGW not fully compatible with sub-tropical based landfills as bulk of the LFG that is produced much early in the biological degradation process would have escaped prior to capture. On the other hand, there has been attempts to consider VGW's as vertical extensions from one terrace to another but this proves challenging to protect during landfilling operations.

The complexity of not having landfill operations compatible with a LFG extraction well led the Engineering and Projects Section of the Department of Cleansing and Solid Waste, DSW to research the design requirements gas extraction systems in supplementing additional LFG to the project. This was seen as a benefit to the project in order to achieve "local data" which would better inform decision making on achieving Certified Emission Reductions (CER's) predications. This probed the need in adopting a LFG extraction system that is compatible in harnessing active LFG early on in the lifetime of a landfill. It was from here that the Engineering and Projects team led to the concept of "Horizontal Gas Wells" (HGW's). To date there has been limited research on HGW use and performance on landfills within South Africa and initial research conducted by Moodley et al, 2010 provided tentative conclusions and at that stage it marked a beginning to a long term research. The overall finding was that the HGW was favoured as opposed to the VGW. Such interim findings were:

- The performance of a HGW was noted to be double that of a VGW. Not only was the HGW flow rate higher but also showed an increasing trend in the CH_4 concentration as opposed to the VGW that reveals a decreasing CH_4 concentration.
- Whilst the initial HGW design only proved a 50% success rate, the revisions adopted and lessons learnt did ensure an improvement to the HGW performance. The revised designs proved that bulk of the LFG supplied to the project in proportion to the number of LFG wells were from that of HGW's.
- Construction Aspects: The HGW proved easier and more practical to construct and install onsite as opposed to the VGW. There is no need for specialist drilling equipment and wells can be easily installed using available landfill resources (excavators, front end loader, site labour etc) and therefore reduces the overall cost per metre.
- Economic Viability: The construction costs of the HGW are approximately half that of a typical VGW making this type of gas extraction well feasible for use.
- Environmental and Social: The HGW is ideally suited for harnessing LFG early on in the lifespan of the landfill. The well has not only delivered additional LFG for methane recovery but has also contributed significantly in preventing offsite LFG migration. This was evident as odour complaints for the Bisasar Road Landfill Site have drastically been reduced after the installation of these wells.

This paper further examines the LFG extraction improvements made since the first research paper and focuses predominately on the life expectancy of a typical HGW through ongoing management of the well field. Lessons learnt in terms of paying attention to LFG "quality" as opposed to "quantity" only should be taken as an important technical consideration. LFG is subject to significantly high concentrations of impurities which result in detrimental effects on gas engine operation and reliability. The combination of increased operating and maintenance costs as well as the resulting engine downtime led to a requirement to implement a low cost landfill gas pre-treatment option to help reduce the LFG impacts on the engines and has proven to be a requirement with any LFG to energy project. Of importance to note the HGW has allowed for additional LFG to supplement to the project but an emerging hypothesis suggests that "newer gas" is much richer in certain impurities and subsequently has shown to have impacts on overall engine operation and maintenance.

The CDM market has been negatively affected by a low issuance rate of CER's in comparison to initial projections, (Lee et al, 2012). Contributing factors can be attributed to site specific technical issues, over estimation, high leachate levels etc. however the Durban experience shows that attention to LFG management can create other opportunities and future developments arising from using LFG instead of LFG to Electricity are briefly highlighted.

2. OVERALL PROJECT 'STOCK TAKE'

The project concept originated in 2003 when it was decided to install a landfill gas extraction and electricity generating plant at the three (3) DSW landfills. An Emissions Reduction Purchase Agreement (ERPA) for Emission Reductions (ER's) was signed with the World Bank in 2004 for all three sites. These being the La Mercy landfill, Mariannhill landfill and the largest site Bisasar Road landfill.

It was initially intended as a single project but due to the delays in the Environmental Impact Assessment (EIA) process and appeals received it was decided to split the project into two components. Component 1 was for a 1 Mega Watt (MW) plant at Mariannhill and a ½ MW plant at La Mercy, for which the Record of Decision (ROD) and Designated National Authority (DNA) approval had been received, and Component 2 for an 8 MW plant at Bisasar Road, for which approval had not been given. It was then agreed that the World

Bank ERPA would only apply to Component 1 as this part of the project was registered as a Clean Development Mechanism (CDM) project and was ready to go to construction. Component 2 has since received a ROD and DNA approval and has been registered as a CDM project with the CDM Executive Board. Construction of the initial 4MW plant at Bisasar Road Landfill being the first stage on Component 2 was completed in April 2008. The second phase which included an additional two 1MW engines and the relocation of the ½ MW engine from La Mercy has increased the plant output capacity to 6.5MW.

The Bisasar Road landfill gas management system was designed with a 5000Nm^3/hr total flow consisting of two (2) 450mm outside diameter (OD) high density polyethylene (HDPE) (nominal pressure up to 12MPa) which allows conveyance of extracted LFG from the landfill to the generation compound. The plant is equipped with two (2) 2500 Nm^3/hr variable speed drives VSD operated blowers that induce a negative pressure on the gas field and this is stabilised by a 2000 Nm^3/hr flare and fed to General Electric Jenbacher (GEJ) spark ignition engines. The pipe work network (better referred to as "fuel carrier" has had careful consideration given to condensate management with knock out pots and attention to pipe grades i.e. in direction of LFG flow allows for minimum 3% whilst in opposite LFG flow direction is typically minimum 5%. Similarly the Mariannhill Landfill gas management system was designed with 1000Nm^3/hr total flow consisting of a single 250mm OD HDPE delivery line to a 1000Nm^{3}hr flare and GEJ spark ignition engine. Bisasar Road has to date some 70 VGW's, 100 HGW's and 70 gas risers which have managed to deliver approximately 4200Nm^3/hr.

LFG monitoring data that will be discussed in the latter section of the paper show that the HGW's and gas risers dominate the bulk of total LFG flow. The LFG gas management at Bisasar Road has rendered sufficient gas at present and has capacity to install another engine but the site is anticipated to reach landfill airspace capacity mid-2015 and the jury is out on how long the LFG is expected to sustain the current 6.5MW generating plant. As a result the project has not opted to install a further engine as it would not prove economically viable in the long term. Hence a further motivation to analyse the extraction well data/performance to assist with future planning for the city.

3. WELL DESIGN AND CONSTRUCTION IMPROVEMENTS

Literature reviews show that the recovery and utilization of LFG using VGW or HGW has been commercialized for 30years with more than 1100 full scale landfill CH_4 recovery operations worldwide (Bogner et al 2005). Conventional models are typically applied using first order kinetic equations to determine LFG productions. These are often based on a set of assumptions such as but not limited to climatic conditions, nature of waste, moisture contents of waste etc. The Durban design experience shows that the modeling estimates cannot be completely relied on as it is not a true reflection of what can be locally achieved. A range of design options for the HGW was initially brainstormed and conservative assumptions were made in HGW design with the ultimate goal of testing the design performance in-situ. Reference is made to the findings from Moodley et al. 2010 with monitoring results unfortunately revealing a 50% success rate with a production of some 40Nm^3/hr.

3.1 FLAWS WITH HGW DESIGN ROUND 1

This design allowed for the gas extraction collector portion of the well comprised of HDPE piping, with the first third (1/3) of the well length installed with 160mm OD pipe. The following two thirds (2/3) of the length were installed with 110mm OD pipe. Both sizes of pipe were perforated to provide an open area of between 4% and 8% of the total wall area. The philosophy in this configuration was to sleeve the solid walled gas collector 1/3 into the HGW length (i.e. 160mmOD) for increased extraction effort along the HGW. The solid walled collector installed was that of a 90mmOD piping.

The rationale in sleeving the collector 1/3 inside the perforated well was to improve the extractive effort across the full length of well. Whilst it proved impractical to excavate and investigate possible failures, subsequent camera footage in similar installations proved that "low points" were formed along the 90mmOD that was sleeved inside the 160mmOD. Such low points results in condensate blockages which in turn inhibits LFG extraction. The most critical finding from this failure was the lesson learnt in giving attention to condensate management.

3.2 HGW DESIGN REVISION – ROUND 2

The lessons learnt from round 1 was considered and emphasis was placed on a design that would negate possible condensate blockages or surging of the well. The immediate practical revisions to the HGW were:

- The entire well length allowed for only an 110mmOD HDPE PN10 perforated to minimum 4% open area. Refer to Figure 1 below for typical cross section of HGW.
- 90mmOD solid walled gas collector sleeved some 2~3m into the 110mmOD HGW hence the mitigation of low points and condensate issues.
- HGW lengths kept to a maximum of 120m as opposed to the initial range of 160~180m. This consideration is not only linked to the extractive effort along the well but more so to limit depth of excavation and allow for safe working open excavations.
- Falls/Gradients on HGW and solid collector lines: This shows to be a critical criteria on any LFG recovery project and due diligence must be given. The design revision called for a minimum of 3% gradients along wells. All collector pipe pipework to be set out onsite with again a minimum 3% fall. Ideally the setting out should allow for continuous knock out of condensate back into the gravel pack of the well. However in places where this cannot be practically constructed, then the setting out allows for a rise in the pipework from the well interface to a high point (generally 3~5%) followed by a fall into the header stations. In this alignment condensate can drain into the gravel pack of the well and into the header station which will knock out/drain into pipework knock out pots. Moreover, where levels on the waste body cannot realise ideal gradients – this seems to be case when waste terraces are in line with header station, then 160mmOD knock out pots are installed at interface of the solid collector and the start of the HGW (refer to Figure 2 below).
- Knock out Pots (KoP) at end of HGW: A conservative approach ensuring that there would be drainage of condensate and or leachate that may pond at the lowest point of the HGW. The KoP is connected generally in a 1m x 1m x1m stone pack sump and guarantees a preferential pathway for any leachate build up, minimising the risk of well flooding. This allows for drainage medium though a hydraulic seal welded to a 90mmOD HDPE pipe that daylights onto side slope faces of the waste body or against the leachate collection drainage layer of the cell. The hydraulic seal prevents oxygen (O_2) ingress and in places are simply formed by lying the collector pipe in an exaggerated "U" and filled with water that forms the hydraulic barrier; refer to Figure 3 and 4.
- In certain areas where landfilled surfaces cannot be excavated to design falls across the length of the well, then in these exceptional cases the 120m well is set out to fall mid-way from either end with a stone pack sump. Since there could be a risk of possible "retention" of leachate/condensate in the sump thereby inhibiting LFG extraction across the blockage and as a result a 90mmOD solid collector is bedded over the sump at an elevated level (typically 2m above with length of 6m) to create a "bridge". This has colloquially been referred to as the bridge design well.

3.3 CONSTRUCTION IMPROVEMENTS

Past construction of HGW's based on the initial design (round 1) challenged the LFG contractor as the required falls were in places in excess of 4m deep. Such deep excavations according to safe construction procedures would typically require shoring to prevent collapse of trenches. Not only is it unsafe but challenged operating plant in placing material (53mm single sizes stone, perforated HDPE pipework, KoP's etc). Given that the Bisasar Road Landfill is positioned in close proximity to a residential area, the construction of the HGW during the excavation phase resulted in an increased number of odour related complaints. Site instructions were issued to the contractor to ensure all excavated waste to be hauled to the working face and odour enzyme dispersion on open trenches was not successful as volume of typical acetogenic waste exposed during construction proved a nuisance. A requirement followed for the team (contractor, landfill operations and the design engineers) to restructure the construction to accommodate safe, practical and social considerations. As a result the following were in order:

- Landfilling terraces to accommodate HGW installation: Initial site difficulties were encountered but with learning, this has been overcome and landfilling programmes now accommodate gas extraction smartly. Landfill operations nowadays realize the benefit in LFG extraction such as reduced long term odour complaints and minimizing LFG offsite migration. Terraces are landfilled with planar gradient which accommodates shallow HGW excavation (generally with 2m depth). This method in landfilling further allows the operator to allow free drainage of surface flow during the rainy season thereby preventing access issues.

- Daily construction targets: Contractor ensures a rate of 50m/day of HGW installation which includes excavation to design levels, bedding of trenches, HDPE pipework welding/drilling, backfill of stone pack, geofabric grade separator installation and backfill to waste body level. This therefore guarantees excavations will be safely and practically completed within a working day and minimizes the probability of odour complaints from the surrounding community. Refer to Figure 3 below for illustration of a typical long section of a HGW.
- Construction quality assurance (CQA): Given that the findings from the initial research required more attention to gradients on pipework, (Moodley et al, 2010) works since then are rigorously checked and approved prior to backfilling of works.

The above revision allows for a HGW to be installed within three (3) days including gas collector's pipework's and installations for control valves and sampling/monitoring points. LFG extraction management of the wells after handover generally start by bleeding the LFG (control valve opened to lower fraction) and this is done to enhance the biological activity. Bleeding of the wells is then commonly commenced by extraction approximately one (1) month after installation.

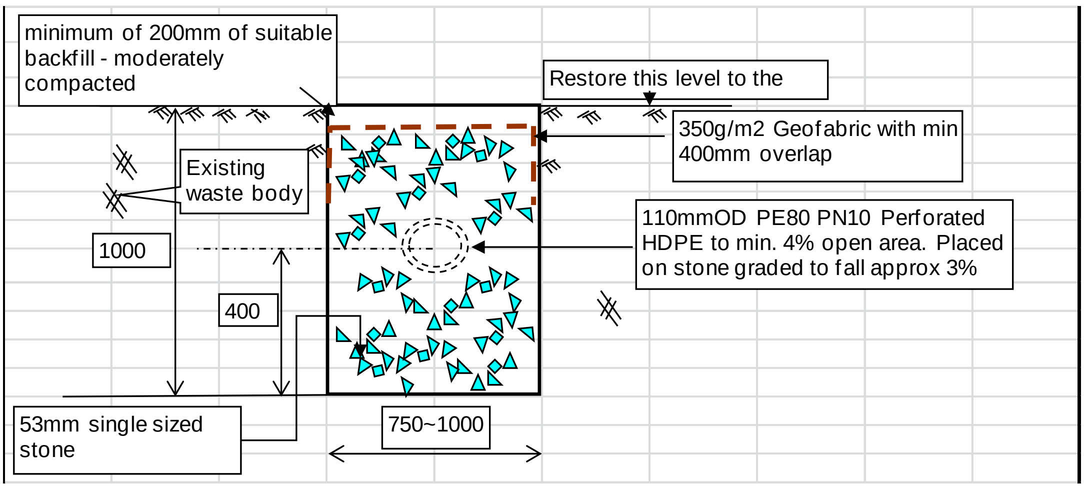

Figure 1: Typical HGW detail – Note to Scale, Moodley, 2011

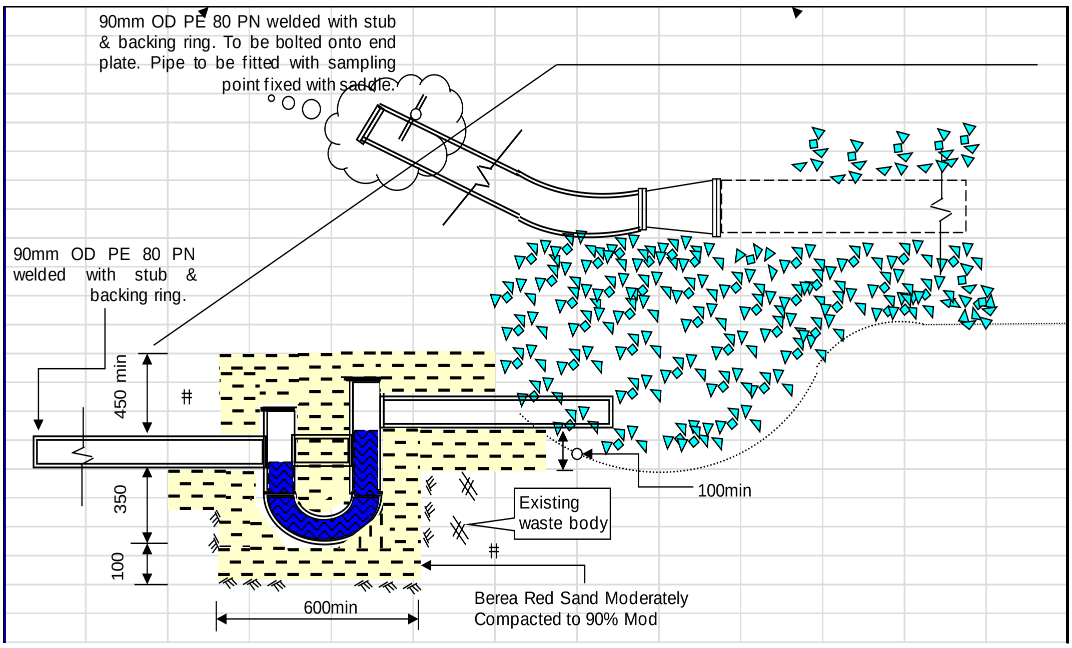

Figure 2: Typical "knock out Pots" – Note to Scale, Moodley, 2011

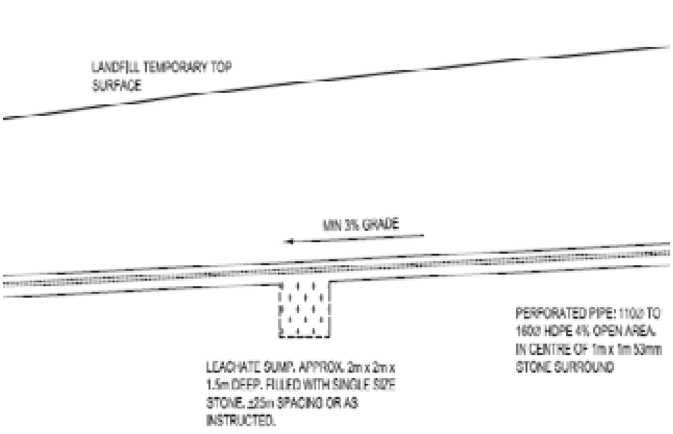

Figure 3: Typical long section through waste body with "sump", Moodley and Pass, 2011

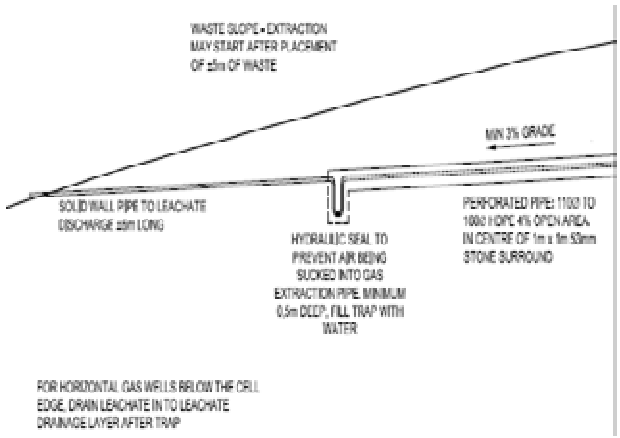

Figure 4: Typical long section through waste body with "knock out Pots", Moodley and Pass, 2011

4. WELL PERFORMANCES AND DISCUSSION

Data collected throughout the investigation included LFG Flow Rate (Q), CH_4 concentration, O_2 concentration, Line Pressure/Suction Pressure and atmospheric pressure as done in initial research. Since this study focused on getting an indication of typical HGW performances, representative wells were selected with monitoring data that covered a historical trend. The selection of HGW's included only those with the revised design and construction in order to get a broad understanding of performance. LFG management was merely based on monitoring gas flows and pressures with fine tuning of the well field and the HGW, although finely bled into the system, was only actively extracted one (1) month after installation. The typical representative HGW's selected in this review were HB V29, HB V30 and HD V1.

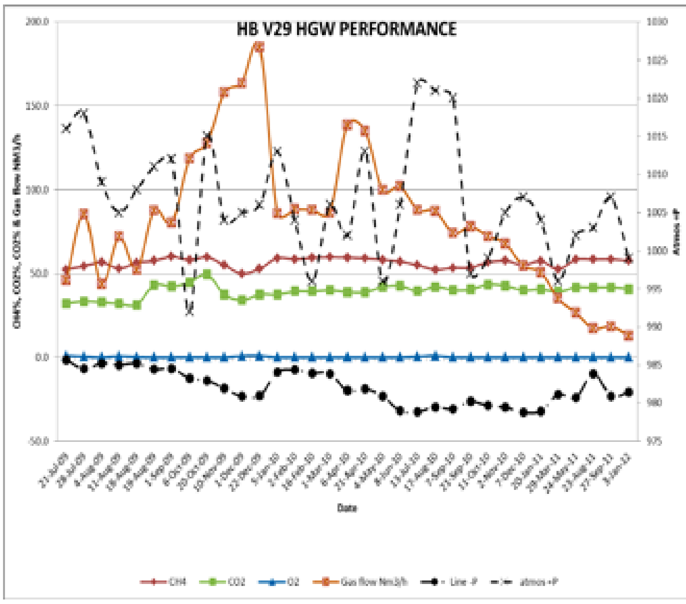

Figure 5 (a): HGW HB V29 Performance

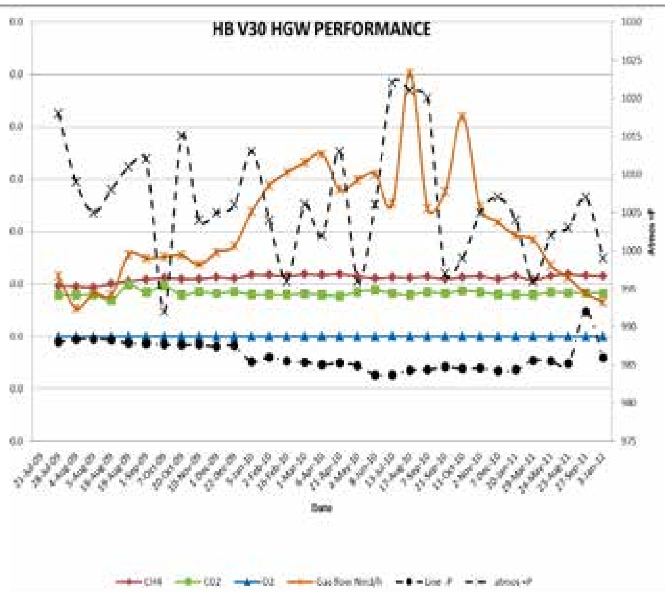

Figure 5 (b): HGW HB V30 Performance

Both figure 5 (a) and (b) represent individual HGW's that were installed at the same time and at similar waste levels. The CH_4 concentration is most pronounced in excess of 50% for HB V29 and V30 and this confirms that gas content of typical young LFG HGWs are rich. Flow rate can be seen to be proportional to that of suction (-P), as suction increases so does the flow rate however CH_4 concentration decreases. It is interesting to note that the O_2 concentration for all the HGW's under review remained/s at 0% and this confirms no leaks in the pipework and further that hydraulic seals are functioning. LFG Flow rate for HB V29 and HB V30 is noticed to peak at some 185 Nm^3/hr and 250 Nm^3/hr respectively! - With an average production in excess of 100 Nm^3/hr. This confirms that of the initial findings from Moodley et al 2010 – that the HGW yields are double that of a VGW.

Figure 5 (a) and (b) above clearly show that both HGW's were actively extracted at the end of June 2009 and were gradually increased into the system up to the latter part of 2010. Flows during this period represent an increased trend and can be substantiated by favourable biological activity. The flows thereafter demonstrate a decreasing trend which is gradual BUT must not be confused with no LFG production! Management of the HGW's shows that these two (2) wells were still active but at low production rate in the order of 30 Nm^3/hr towards early 2012. The life prediction of HB V29 and HB V30 can be seen to have maintained performance for some 3years

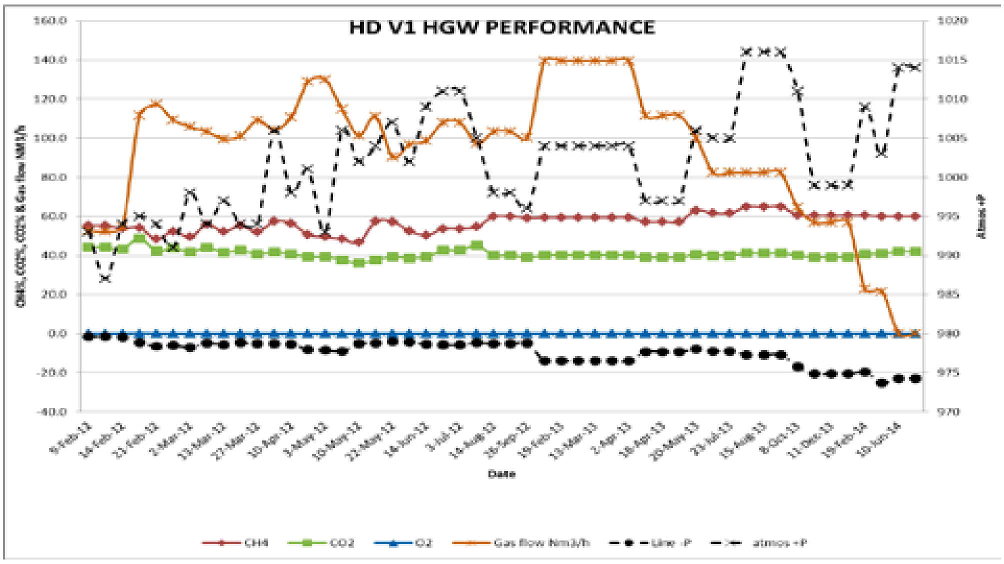

Figure 5 (c): HGW HD V1 Performance

Similarly, Figure 5 (c) above depicts a comparable trend to the behaviour HB V29 and HB V30 with an average flow rate of some 100 Nm^3/hr and is noted to peak at 140Nm^3/hr. There was no evidence of spikes in O_2 during monitoring which demonstrates that wells were properly managed and hydraulic seals functioning. The CH_4 concentration however is much richer (above 55%) and this is indicative of young landfill gas quality. Again it can be seen that the flow rate is proportional to the negative pressure applied to the HGW however, HD V1, although maintaining a high CH_4 content stopped producing some 2.5 years into its life. Possible failure could be attributed to excessive differential settlement in the waste body leading to low points in the collector line etc.

Overall the snapshot presented in this section confirms that LFG can be accessed soon after waste placement and production rates of typical HGWs are some 100 Nm^3/hr. The life time predications of HGW's at this stage are not fully conclusive but the overall performances seem to show a 3year active production thereafter decreasing to fairly low yields. Monitoring data also reveals that the revised HGW design shows no signs of immediate or short term failure. This validates that the design and construction improvements are successful as opposed to the initial design that only had a 50% success rate.

5. COMPARISON OF PROJECT GAS PREDICTIONS TO ACTUAL FLOW DELIVERED

To date landfill gas CDM projects have been inundated by a low issuance rate of CER's compared to initial projects. The poor performance can be due to optimistic estimation of emission reduction at project conception phase, (Lee et al 2009). The GasSim model was used for LFG predication and whilst one can argue the compatibility of this international model to a South African context, LFG predications were done in the early stages but not questioned whether targets could be realistically achieved. The department is underway with predicting the volume of LFG that is anticipated to be collected from Bisasar Road in the future. However Figure 6 below shows the estimated gas flows needed to achieve the ER targets in the Project Design Document (PDD) versus what is actually delivery to the project.

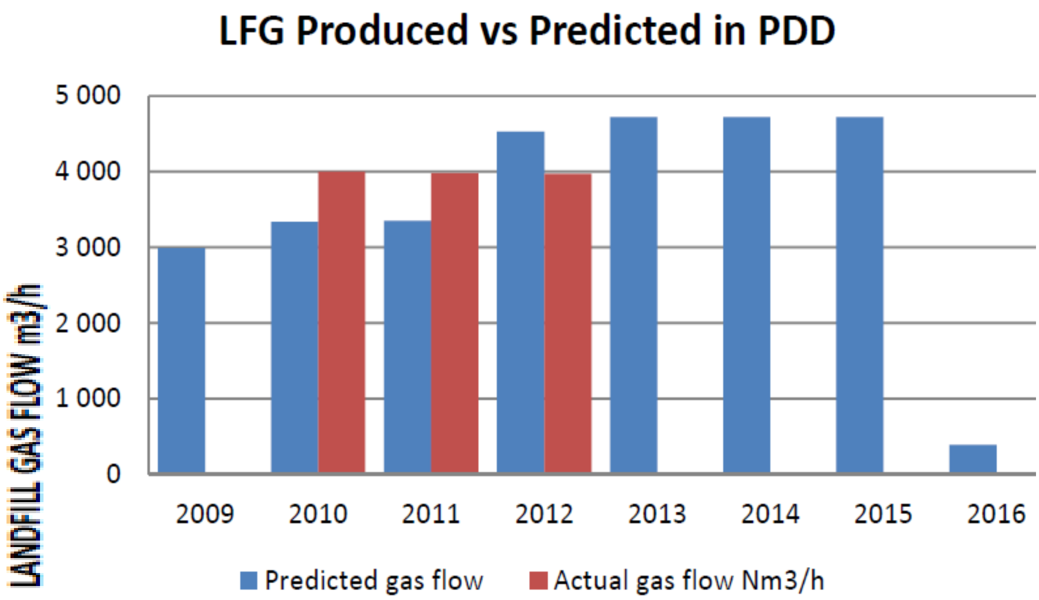

Figure 6: Actual LFG flows compared with Initial Predication

It can be clearly seen from Figure 6 above that actual LFG flows delivered to the LFG to electricity plant have exceeded that of the predictions in the PDD. The introduction of the HGW's has conveyed additional LFG to the Durban Landfill Gas to Electricity Clean Development Mechanism (CDM) project and guarantees that future Certified Emission Reductions (CER's) for the project will be achieved provided there is sufficient HGW installation. The Bisasar Road component two project is expected to produce some 250 000 CER's tCO_2e per year up to the closure of the site which is imminent around mid-2015. It is expected that the total LFG flow will thereafter decrease towards 2018 which may affect future deliverance of ER's for the project.

Although the improvements made by the team to optimise the HGW's to enable meeting such ER targets, it is unfortunate that interpretation of the baseline methodology used for the project (being AM0010) by the verifiers excluded ER's for flaring. On the contrary the Mariannhill Component 1 project has the identical methodology but ER's were included for flaring? Correspondence in this regard is underway with the UNFCCC secretariat to either have the project reregistered under clear and definite methodology i.e. ACM0001 or look at options to trade flaring credits under the voluntary market. The point to be highlighted under this argument is that the exclusion of ER's from flaring has placed additional strain on the project as a whole should the LFG flow predications not be met. The HGW has clearly managed to satisfy the requirement in extracting LFG soon after waste placement.

6. BEYOND THE WELL – FUTURE OPPORTUNITIES

The current low issuance rate of CER's in comparison to initial projections as well as current poor CER market trading is causing many existing and new project owners to investigate alternative sustainable options to manage LFG. The Durban experience has proved that the landfill gas to electricity back into the municipal power supply grid can be realised but challenges with complexities in methodologies, risks in the CDM market, etc. are creating frustrations. A wealth of knowledge has been gained – in excess of ten (10) years - with local LFG extraction, optimisation and overall field management whereby delivery of LFG is well understood. Further landfill sites are the industry's most safe bankable and cost effect waste management option which will ensure LFG being a resource for the medium to long term.

As a result the department is investigating upgrading options of the LFG i.e. cleaning the LFG to pipeline gas or vehicle fuel quality. However the costs in upgrading the LFG at this stage require high capital and operating expenditure (1200 Nm^3/hr plant using activated carbon/membrane technology are in the order of R20million capex). At this stage the use of the LFG upgraded as a fuel for collection fleets seems lucrative. A motivation for eThekwini to invest in a pilot study in this area may prove project viability with the closure of Bisasar Road, as domestic waste will be required to be long hauled to the northern regional landfill i.e. Buffelsdraai Landfill. The market increases in crude oil coupled with the emissions from existing diesel collection fleets may render this as the next (or possibly complementing) opportunity for the landfill industry.

7. CONCLUSIONS

As the South African landfill industry has little research on the performance of horizontal gas extraction wells, this ongoing research initiative provides an insight to HGW performances and life expectancies. The monitoring of data for the project has been to build a historical database which will better inform technical decision making for future projects. The investigations/monitoring results thus far show that the production of a HGW in terms of flow rate is on average some 100 Nm^3/hr and life expectancy in general is some 3years at this stage and the jury is still out on how long one can expect a sustained LFG yield.

This simple low cost practical option using HGW's is ideally suited for harnessing LFG early on in the lifespan of the landfill. The well has not only delivered additional LFG for methane recovery but has also contributed significantly in preventing offsite LFG migration. The design and construction amendments has allowed for an increased success rate and ensured valuable lessons for the project team. The PDD predications of LFG flows are currently being met and confirm the success in adopting HGW extraction for project. Overall there will be a reduction in GHG emissions from landfill sites, providing reasonable protection of the global climate.

The current poor performance of the CDM market coupled with the low issuance of CER's has necessitated the need to explore alternative use of the LFG other than LFG to electricity such as upgrading the gas for vehicle/collection fleet use and these options may inform future opportunities given the markets demand for alternative fuel sources.

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