# WELL, WHICH WELL?

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ABSTRACT

The Durban Landfill Gas to Electricity Clean Development Mechanism (CDM) project has been Africa's first *Landfill CDM Project* and grown to the potential for electricity generation and receiving revenue from methane ($CH_4$) destruction in the form of Certified Emission Reductions (CER's). Seeing that Durban is sited in a sub tropical climate, results in significant quantity of landfill gas (LFG) being produced early in the life of the landfill with a high $CH_4$ content and this could be re-directed to power additional generators. Therefore the Department of Cleansing and Solid Waste, DSW had placed emphasis on studying the design requirements of horizontal gas extraction wells, its integration into gas collection systems and its performance. This paper presents experience with designing, constructing and operating LFG collection wells. The project gas flows and yields are discussed however and tentative conclusions are drawn to show improvement to the project performance and LFG management.

## 1. INTRODUCTION

Landfill gas has been seen to be one of the most important environmental parameters for a landfill of Municipal Solid Waste (MSW). Methane ($CH_4$) and carbon dioxide ($CO_2$) are the by-products of biological degradation under anaerobic conditions and have proven to be the major "ingredients" of landfill gas. It is the methane fraction that has been confirmed to be the significant contributor to global warming, with a global warming potential 21~25 times that of carbon dioxide. As a result, this has created opportunities for numerous landfill methane emission reduction projects to be implemented in developing countries. An example of such a project is the Durban Landfill Gas to Electricity Clean Development Mechanism (CDM) project.

This project is *Africa's first Landfill Gas to Electricity CDM Project* and with the growing emphasis for alternative energy demand, makes it one of the most attractive South African success projects. In order to meet Certified Emission Reductions (CER's) predictions and coupled with financial rewards from the project, the Engineering and Projects Section of the Department of Cleansing and Solid Waste, DSW has commenced research into studying and optimising the design requirements gas extraction systems in supplementing additional LFG to the project. An additional reason for this was as a result of there being little to limited experience with designing, constructing and operating such LFG collection systems locally within South Africa. Although there have been many case studies in the international spectrum, there is no comparison on the performance of typical LFG collection systems locally as there is complexity in spatial variability such as types of waste, climatic conditions etc.

The pioneering system of LFG extraction is undoubtedly the Vertical Gas Extraction Well (VGW) and has been in use since the mid 1960's to early 1970's, (Darrin, 2005). Literature reviews show that due to the VGW's common use in the landfill industry, its design and performance was always accepted but not questioned. This has to some extent overlooked the basic fundamentals in the principles of LFG extraction as designs were based on empirical observations. Initial gas extraction from the well field was based on VGW's and gas risers from the leachate drainage layers. LFG production from the gas riser pipes proved to deliver relatively higher LFG production than the VGW. Seeing that 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 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).

There has been little research to date on HGW performance on landfills within South Africa, and therefore there are very little documented well performances between VGW’s and HGW’s. The curiosity of this aspect further to the need of supplementing additional LFG as soon as possible for methane destruction and electricity generation triggered a comparative study of both systems in-situ at the Bisasar Road Landfill Site in Durban, Kwa-Zulu Natal. This paper highlights the start of a long term study of the HGW performance and therefore presents preliminary findings. The landfill gas collection systems on eThekwini Metropolitan landfills are primarily operated for energy recovery and emission control purposes but now through the introduction of HGW’s, it has notably reduced the odour complaints from the surrounding communities. This can also be seen as a tool in combating LFG migration which is beneficial any landfill operator.

## 2. LANDFILL GAS EXTRACTION

Historically LFG extraction systems have been mainly implemented in capturing LFG generated within the landfill waste body to achieve some sort of compliance. This “programmed” approach has resulted in landfill operators not focusing on the LFG collection efficiency but rather satisfying legal compliance limits. These systems are typically designed to control LFG migration from a health and safety point of view and more importantly limit Greenhouse Gas (GHG) emissions. The LFG extracted can be managed using the following systems:

- *Passive Gas Control Systems*: This type of system mainly relies on pressure or concentration gradients between the LFG within the waste body and the ambient air to function. The system may not include treatment prior to discharge in the receiving environment.
- *Active Gas Control Systems*: A more commonly used system on landfills that allows for a ‘carrier’ which creates a vacuum on the landfill. Active systems rely on blowers to induce a negative pressure to move LFG through a collection system destined for treatment.

The above systems can be installed to work independently or in combination together. However, active LFG extraction, collection and treatment systems have proven to be ideal for gas management. The extraction system opted for will tap into a biological field source of $CH_4$ and it is on this basis that the system mass balance must be understood for ease of extraction. Figure 1 below illustrates a typical methane mass balance within a landfill.

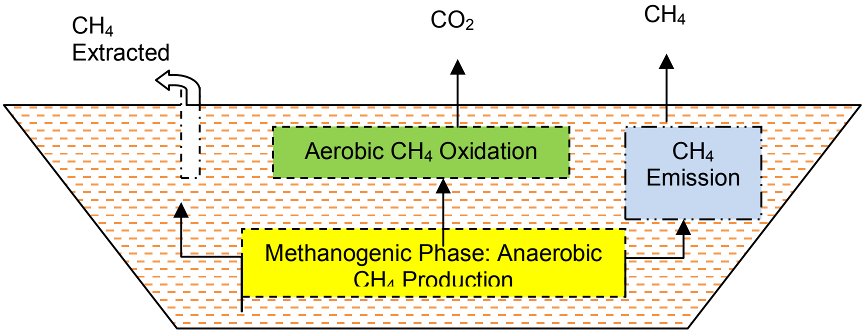


Figure 1: Schematic representation of Methane mass balance within a landfill

## 3. DESIGN CONSIDERATIONS

Undoubtedly the design of gas extraction systems will be site specific and given the nature of the Durban Gas to Electricity Project, the design team selected an active LFG control system. The system is monitored regularly for leaks, condensate build ups, surging in collector lines and well field balancing. The header design used consists of a “loop design” i.e. two (2) 450mm OD HDPE pipes along the site perimeter with strategically placed isolating valves, balancing valves and condensate knock out pots for effective gas management. The overall design philosophy adopted is one of a phased approach to adequately satisfy system treatment needs and economic viability.

With the core objective of having minimal downtime to the spark ignition LFG engines, emphasis was placed on deigning a new extraction system that could easily be isolated in the event of repairs/ shutdowns but more so for increased control of individual gas extraction wells.

Having considered the types of LFG systems and gaining an overview of the biological degradation process as well as the design considerations, it is now appropriate to address the purpose of this paper which is to answer the question: *Well, Which Well?* The two (2) types of LFG extraction wells in consideration are the Vertical Gas Well and the Horizontal Gas Well. Both satisfy the need of feeding landfill gas from wells through pipe work and fed to spark-ignition type electrical generation units, with any surplus gas, or “spill-over” gas being flared.

## 3.1 VERTICAL GAS WELL EXTRACTION (VGW)

As mentioned earlier, VGW’s have been the most commonly used extraction well in the landfill application and seeing that well details are easily available, designers normally used these without it being tailored to site specific applications and results in relatively expensive blueprint that may not perform as expected (Darrin 2005). The VGW’s installed at the Bisasar Road Landfill were installed based on the international rule of thumb and empirical observations with no site specific studies being done. Wells were positioned on final terrace levels range from 35m to 50m well spacing centres within the internal area and pegged a minimum of 30m from side slopes to prevent oxygen ($O_2$) ingress.

### 3.1.1 Typical VGW Detail

The well assembly and wellhead requirements for the system design are as follows:

- The well head and well is constructed of HDPE. Individual well heads chosen are of the Hofstetter GBA type and incorporates a gas flow regulator which enables the well to be completely shut off (0%) and fully opened (100%). Wellheads are connected to the pipework by means of bolted flanges at the wellhead welded that allows for differential settlement of the waste body and interconnecting pipework are HPDE butt joint welded.

- Wellheads are equipped with gas sampling points (a flow/temperature monitoring point), a flow control/isolating valve and a leachate/condensate dip point. The Hofstetter GBA type has the facility to allow a leachate/condensate pumping system to be installed in the well and the leachate pumping system ensures that the leachate does not rise by more than 2m above the base of the well. This system therefore was seen at the initial stages of the project as versatile as LFG could be recovered as well as leachate/condensate at the same time.

- The gas extraction portion of the well shall typically comprise at least HDPE piping with a minimum Outside Diameter (OD) of 160mm. This portion of the well is perforated to provide an open area of between 4% and 8% of the total wall area.

- The annulus between the hole formed in the refuse for well installation and the well is filled with a gravel pack comprising 13mm single sized, hard durable non-carbonate crushed stone. The upper portion of the well is sealed with a minimum of 1m of bentonite, two layers of geofabric, 150mm of stabilised sand soil and 100mm of 19mm single sized crushed stone in the annulus between the wellhead and housed in a 1000mm precast concrete manhole ring.

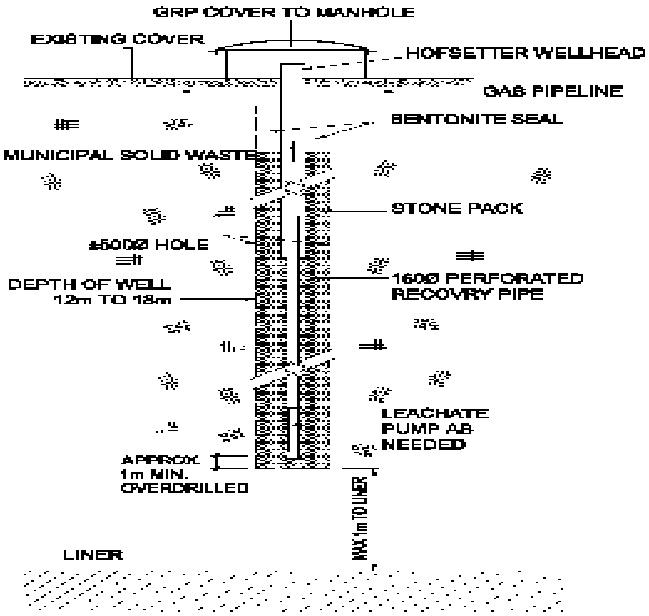


Figure 2: Typical Section through a Vertical Gas Extraction Well, (Moodley L, Wilson & Pass, 2009)

Figure 2 above can be used as a visual tool to understand the dynamic set up for this type of extraction well. A sophisticated design that requires careful installation onsite by competent contractors as experience has shown onsite construction challenges. Well borehole forming required specialist equipment such as drilling rigs and seeing that the forming is in compacted Municipal Solid Waste (MSW), there is risk of collapse, obstructions and leachate inflows. This not only delays the contractor but holes have to be abandoned, backfilled and made safe. Effective well depths at the Bisasar Road Landfill Site vary from 8m to 25m but however limited to the drilling capacity of the drilling rig.

There have been attempts to increase the drilling flight beyond 25m but holes were witnessed to collapse during the changing interval resulting in either a reduced well bore length or even cases of total abandonment. Based on this observation, the VGW have shown not only difficult to install but also relatively expensive when factoring in all the materials required and special resources required for construction.

Differential settlements on landfills are an added concern for this type of well as leachate extraction pumps become wedged inside the well thereby losing leachate management for that particular well and this inhibits LFG extraction. “The Durban experience” has shown that a landfill operator with such a system should factor in 10% loss in leachate extraction pumps per annum.

Past research on landfill emissions in sub-tropical areas by A. Bowers, 2002 showed that at least 70% of LFG is produced with the first 2~3 years of the landfill. Since this type of VGW is mainly installed at final terraces which can take a long time to landfill, it loses the potential of “early gas extraction” as majority of the LFG would have been already vented. Figure 3 below depicts such and substantiates this argument. Hence this necessitated a shift in the engineering philosophy to adopt a LFG extraction well that addresses harnessing LFG as soon as possible at a relatively lower costs and one that accommodates effortless construction. As a result, the decision was obvious to install and study Horizontal Gas Extraction Wells (HGW).

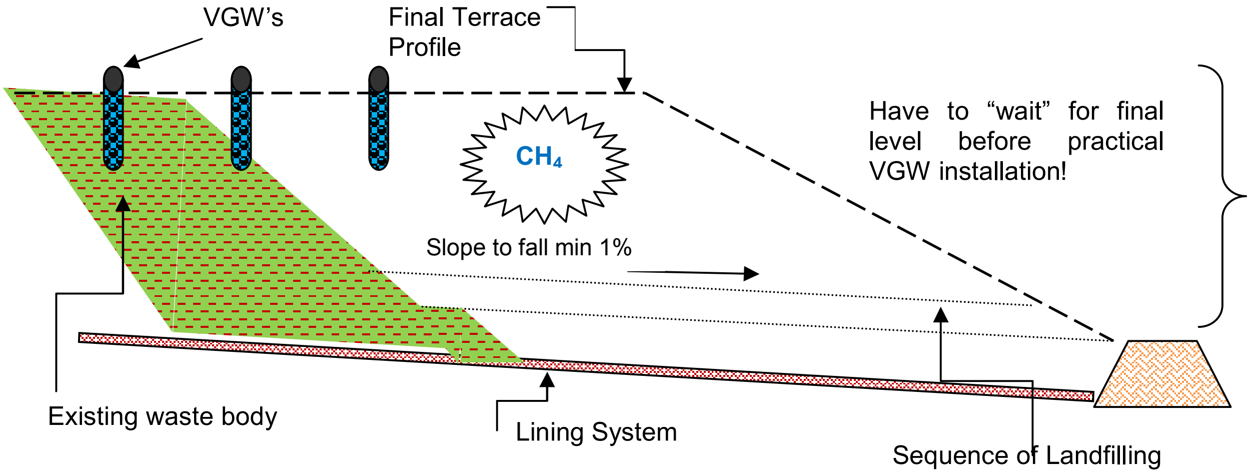


Figure 3: Typical Section through Landfill illustrating VGW installation - NTS

## 3.2 HORIZONTAL GAS WELL EXTRACTION (HGW)

Horizontal Gas Wells are not new in the industry however its design and performance is not well understood as there has been limited research on landfills. Although literature reviews document HGW use internationally, the Engineering Projects Sections raised interest in this type as the existing gas risers from the cell leachate drainage layers revealed better LFG performance as compared to the VGW's. These risers were viewed by the team as "horizontal LFG collectors" and therefore set the basis for the design principles of HGW's. Logic will prevail from this study that HGW's are most suited for active cell LFG extraction, Gregory P, (2005) as their major advantage versus the VGW are their compatibility with active landfill operations and their ease of installation.

### 3.2.1 Typical HGW Detail

At the outset of this study conservative assumptions were made in HGW design with ultimate goal of testing the design performance in-situ. The first design was as follows:

- 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.

- Emphasis was placed on individual well control as experience has shown that more isolation valves allow for enhanced LFG management with minimal effort.

- The annulus between the horizontal trenches on active cells in the refuse was filled with a gravel pack comprising 53mm single sized, hard durable non-carbonate crushed stone.

- The upper portion of the well was compacted with a minimum of 150mm of waste or cover soil, a layer of geofabric with a minimum of 300mm overlap down the side slopes of the trench, 400mm of 53mm single sized crushed stone in the annulus between HDPE perforated pipe and the base of the well. Refer to figure 5 below.

- A manifold was designed to accommodate individual HGW connection and in turn was fitted with a condensate knock out pot that ensured a hydraulic seal thereby preventing oxygen ingress into the system. These manifold stations which are termed “Header Stations” were strategically positioned along the cell perimeter away from the interference of daily landfill operations and these were linked into the main header lines in the active loop design. Refer to figure 6 below.

- Each HGW was fitted with a sampling point compatible for monitoring temperature, LFG concentrations, pressures and gas velocities. This allows efficient monitoring from which the data could be used by the extraction contractor to make educated decisions/fine tune well field etc.

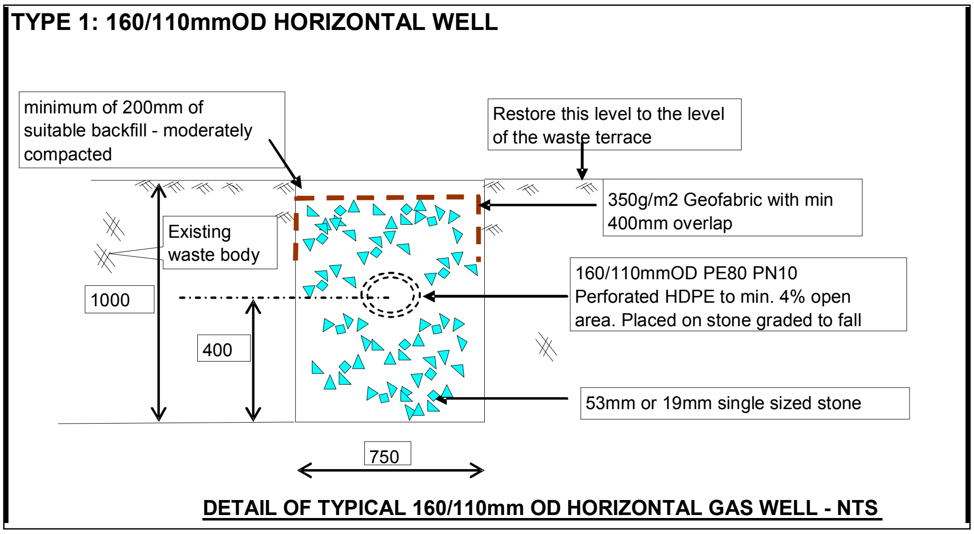


Figure 5: Typical Section of Initial HGW – NTS

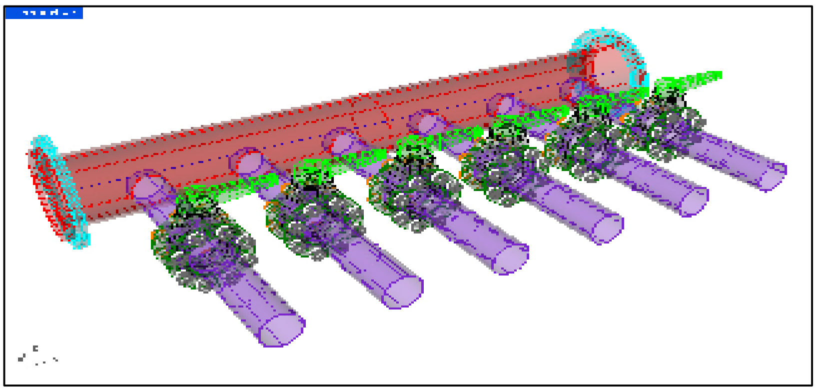

Figure 6: Typical 3-D view of Manifold Module used for individual HGW connection

A total of six (6) HGW’s were installed with this type of design and monitoring results unfortunately revealed a 50% success rate with a production of some 40Nm$^3$/hr. To date the reason for poor performance design is not explained as unsuccessful investigations were attempted to excavate these HGW’s and inspect. Each terrace is some 3m deep and seeing that this was on active cells, proved it difficult to practically do so.

It is assumed at this stage that the 90mm OD solid pipe that was sleeved into the HW had formed low points. There is reason to believe that as a result of excessive temperatures within the waste body (>70$^o$C) had subsequently led to the solid walled pipe “heaving” which inhibits condensate removal. Results from these poor performing wells show temperatures within the well to be some 30-40 $^o$C. It would then follow that there is a higher probability for condensate production due to this temperature difference and the effect of gas movement through a cooler medium. Further explanation could be due to questionable HGW installation and minimum falls/grades of well length. Revised HGW design considerations included the following:

- 160mmOD HW changed to 110mmOD along entire well length.
- 90mmOD solid walled gas collector sleeved some 2~3m into the 110mmOD HGW. Emphasis placed on condensate knock out of gas collector line as this physically delivers LFG from well to header stations.
- Falls/grades on HGW increased.
- More stringent control and quality check of installation.
- Condensate draining sumps installed at low point of HGW's with some wells fitting with hydraulic seals and overflow consendate pipes laid from sumps to edge of cell side slopes. The intention of this was to quantify if condensate/leachate did accumulate within the HGW.

A total of ten (10) HGW's has since been installed with the revised design considerations. Results from the <u>revised HGW's have shown improved gas well production performance</u> and to date there has been no well failures. These ten wells are now producing a quarter of the total gas field production. An interesting note to highlight is that the HGW bore-length is significantly longer than that of VGW's i.e. ranging from 120m to 180m and therefore *comparison of systems should be made on LFG production per unit length* rather than LFG production per well. Moreover, performance will be discussed in the next section.

## 4. WELL PERFORMANCES AND DISCUSSION

Pertinent data collected during the study included LFG Flow Rate (Q), $CH_4$ concentration, $O_2$ concentration, Line Pressure/Suction Pressure and atmospheric pressure. Since the study focused of comparing VGW and HGW performances, representative well sets were selected with monitoring data taken from the same time frames. This was done in order to give a picture of LFG collection efficiency. Monitoring intervals during the early stages were conducted more frequently with one interval per week and gradually extended to once a month as the gas field balanced. It is crucial to know that it takes approximately four (4) months to balance a gas field as the rate of LFG production is dependent on the biological degradation within the waste body. A guideline used for extraction management is that $CH_4 \geq 45\%$, $O_2 \leq 1\%$ and $CO_2 \geq 35\%$. Management is merely based on monitoring gas flows and pressures with fine tuning of the well field taking up to a week to show results to the gas to electricity plant. The typical/representative vertical gas wells under study are that of HC-V19-GW and GW-RM-22 whilst the horizontal gas wells are represented by HB-V29-HWLC and HB-V30-HWLC.

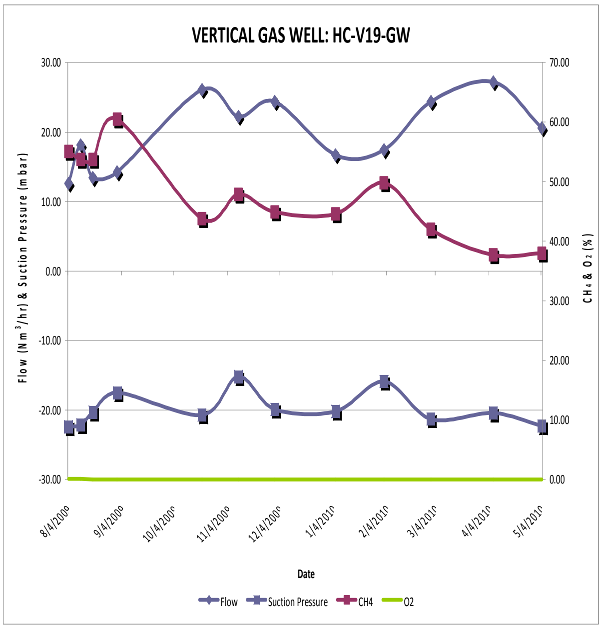


Figure 7(a): Vertical Gas Well HC-V19-GW

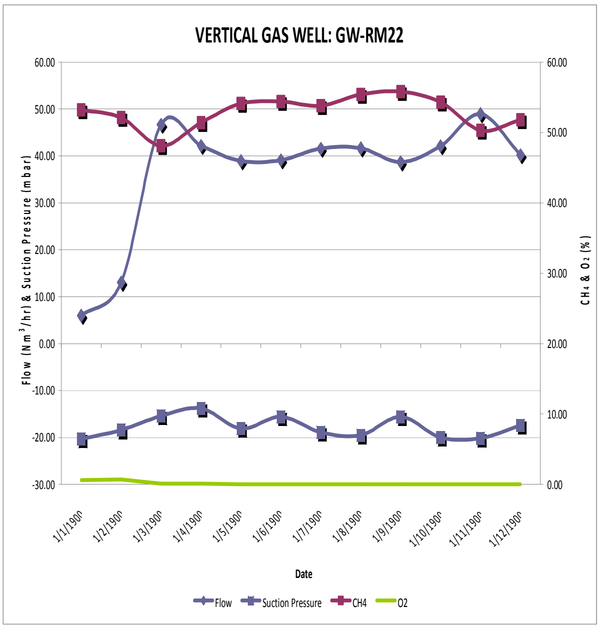


Figure 7(b): Vertical Gas Well GW-RM22

Figure 7(a) above clearly shows a <u>decreasing trend in $CH_4$ concentration</u> to some 40%. This was expected as VGW's in this area where drilled through fairly old waste and as a result in fairly low biological activity. Flow rate can be seen to be proportional to suction, as suction increases so does the flow rate however $CH_4$ concentration decreases. Such system dynamics were as expected nevertheless yielding some 60Nm$^3$/hr of LFG with an increasing trend.

Similarly, Figure 7 (b) (GW-RM22) follows in comparable trend to the behaviour of HC-V19-GW with a $CH_4$ concentration of some 55% and a flow rate representing an increasing trend of approximately 40Nm$^3$/hr. Both wells show no evidence/spikes in $O_2$ monitoring which demonstrates that wells were properly managed.

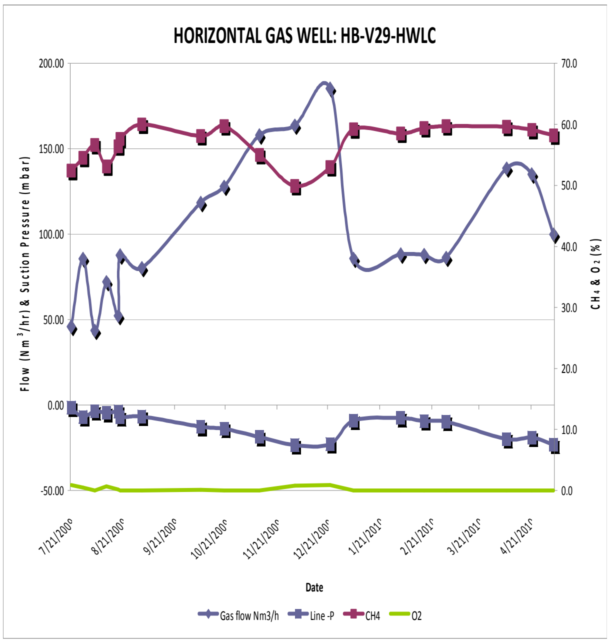


Figure 8(a): Horizontal Gas Well HB-V29-LC

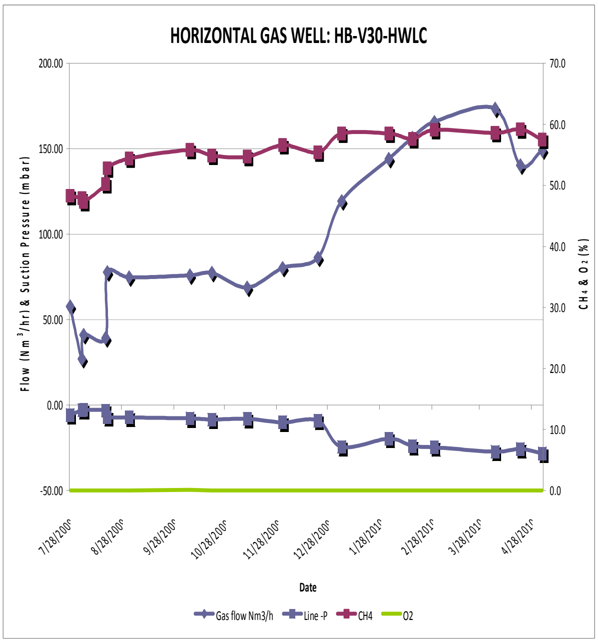


Figure 8(b): Horizontal Gas Well HB-V30-LC

Figure 8(a) above depicts an increasing trend in $CH_4$ concentration as opposed to the trend recognised in the VGW's. Concentrations seem to settle out just below 60% $CH_4$ and this pertinent observation reveals that the LFG is fairly "rich". Seeing that this type of well was installed in fresh waste and monitoring began a week after installation, shows the advantage of the use of this type of extraction well to harness such concentrated LFG. Flow is generally proportional to the suction pressure and as a result the demand on the gas field/well increased biological activity. The flow rate also confirms this theory as there is a gradual increase in trend <u>averaging some 120Nm$^3$/hr</u>. This is an imperative finding which shows that the LFG production of a HGW is double that of a VGW!

Similarly, Figure 8 (b) (HB-V30-LC) behaves in the same fashion as HB-V29-LC with a $CH_4$ concentration of some 57% (yet again very rich methane) and displacing and increasing flow rate trend averaging to an even higher 160Nm$^3$/hr. Monitoring results show that there is still potential to extract more from this type of gas wells (HGW) as there is no evidence of oxygen (0%) been drawn into the well. The relatively high $CH_4$ concentration is indicative of young landfill gas quality.

Figure 9 below best describes the comparative performance between the representative study set of gas extraction wells. The objective of this figure illustrates the total percentage contribution of LFG produced in relation to the total number of the specific well type. Currently there are some 62 VGW's installed, 10 HGW's and 9 Risers (R) mains (each consisting of four (4) risers per main) installed at the Bisasar Road Landfill Site. The total LFG supply or rather flow to the gas to electricity plant is just under 4200Nm$^3$/hr at 52% $CH_4$. The figure below easily illustrates that only 12% of the total well proportion contribution by HGW supplies some 26% of the total LFG (from just 10 HGW's!) to the project i.e. a lower well proportion yields a higher gas production. The risers depict a similar pattern with 11% of the total well proportion delivering 33% of the total LFG. However, the VGW illustration shows the opposite trend i.e. 77% of the total well proportion yields 42% of the total LFG produced i.e. a higher well proportion for a lower gas production compared to the HGW. This is another finding from a cost benefit point of view that makes the HGW advantageous over the traditional VGW.

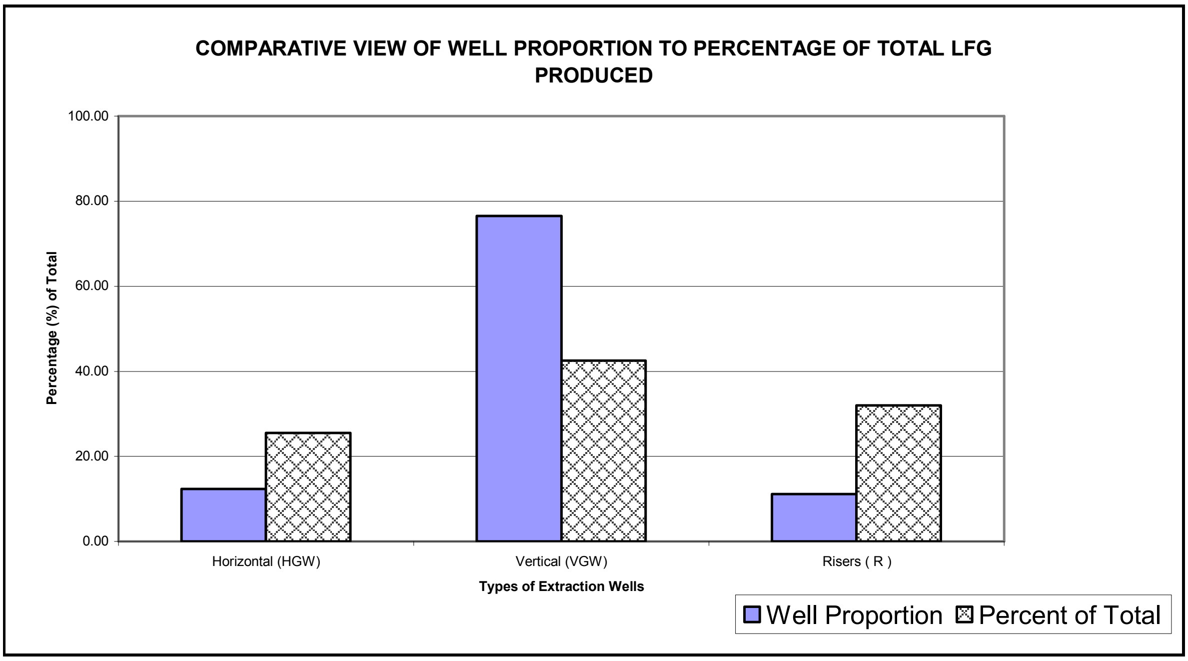


Figure 9: Comparative view of Well Proportion to the Percentage Total of LFG Produced

## 5. CONCLUSIONS

There has been limited research to date on the performance of horizontal gas extraction wells in landfills within South Africa, and therefore this research initiative provides an insight to comparative views between the traditional vertical gas well and the horizontal gas well. The data presented in this paper marks the start in building up a historical database on these well performances and therefore only tentative conclusions are drawn at this stage.

- Preliminary monitoring data at this stage explicitly show that LFG production of a HGW is higher than those of a VGW by approximately double the production. Not only is the HGW flow rate high but also shows an increasing trend in the $CH_4$ concentration as opposed to the VGW that reveals a decreasing $CH_4$ concentration. Results shows that the LFG production of a HGW is double that of a VGW!

- The revised HGW design implemented to ten (10) HGW's are contributing some 26% of the total LFG supply to the gas to electricity plant. This is adequate to fuel two 1 Mega Watt spark ignition engines. The exceptional performance of this well has now proven that additional LFG can be supplemented 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 HGW has shown that it is much easier/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.

- Seeing that the project is sited in a sub-tropical environment, 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 is evident as odour complaints for the Bisasar Road Landfill Site have drastically been reduced after the installation of these wells. Further evidence in curbing such migration is in the environmental indicators for the site as rehabilitation of closed cells is thriving.

- A true decision maker to any engineering project predominately rests on its economical viability. It would then follow from this note that the total cost of a HGW is approximately half that of a VGW making this type of gas extraction well feasible for use.

In the bigger vision of the project, operations and maintenance of the LFG control system requires expertise with the control system and monitoring equipment and on this basis should not be treated lightly. It is strongly suggested that any LFG to energy project owner build up a competent team to cover all aspects in order to achieve project success.

The Durban experience of HGW installation has shown that it must "marry" with that of the landfill operations team. Initial site difficulties were encountered but with learning, this has been overcome and landfilling programmes now accommodate gas extraction smartly. Another concluding remark from this study is that *Condensate Management* requires the due care that is deserves for efficient LFG extraction.

The above results and discussion sets the foundation to this long term performance monitoring project and finally the title of this paper being a question: Well, Which Well? can now be answered…..*THE HORIZONTAL GAS EXTRACTION WELL!*

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