Measurement of Representative Landfill Gas Migration Samples at Landfill Perimeters: A Case Study

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ABSTRACT

This paper describes the development of a fully integrated autonomous system based on existing infrared sensing technology capable of monitoring landfill gas migration (specifically carbon dioxide and methane) at landfill sites. Sampling using the described system was validated against the industry standard, GA2000 Plus hand held device, manufactured by Geotechnical Instruments Inc. As a consequence of repeated sampling during validation experiments, fluctuations in the gas mixtures became apparent. This initiated a parallel study into what constitutes a representative sample of landfill gas migration as reported to the Environmental Protection Agency. The

work described in this paper shows that gas mixture concentrations change with depth of extraction from the borehole well, but with evidence of a steady state after a time.

KEYWORDS

Landfill gas, sensors, environmental monitoring, gas sampling

INTRODUCTION

At present, there is great global concern over the state of the environment. The production of greenhouse gases has led to global warming which in turn has led to increased water levels around the planet and from here the domino effect carries on and on. In short, the state of the planet is something of concern to every inhabitant of Earth irrespective of territorial boundaries. Reduction in pollution needs management and monitoring and so, the design of robust, reliable environmental monitoring devices and the development of reliable, accurate sampling methods have never been more necessary.

There are a number of major greenhouse gas contributors including landfill gas emissions, the main components of which are carbon dioxide and methane, both greenhouse gases. In this paper a novel landfill gas monitoring unit and a reference unit will be used to carry out a study to ascertain the most appropriate sampling method for a representative gas sample from a perimeter borehole well.

LANDFILL GAS

Landfill gas is defined as all the gases generated from landfill waste.[1] Studies have shown that the components of landfill gas (produced through the degradation of biodegradeable waste in the landfill) are mainly methane (40-60 %), carbon dioxide (40-60 %) and other trace gases (~1 %) known as volatile organic compounds (VOCs).[2] Landfill gas is of interest because the main components, methane and carbon dioxide are greenhouse gases with global warming potentials of 21 over 100 years and 56 over 20 years in the case of methane, while carbon dioxide is normalised to 1 in both cases.[3] Additionally, methane is a flammable gas. This trait can be exploited by using landfill gas as a fuel.

The EC Council Directive 1999/31/EC states that "…like any other type of waste treatment, landfill should be adequately monitored and managed to prevent or reduce potential adverse effects on the environment and risks to human health…" and "…measures should be taken to reduce the production of methane gas from landfills, *inter alia,* in order to reduce global warming, through the reduction of the landfill of biodegradable waste and the requirements to introduce landfill gas control".[1]

There are currently 81 licensed sites in Ireland, only 36 of which are active.[4] Still, capped landfills can produce significant quantities of landfill gas and require monitoring. Landfill gas production is unpredictable in closed sites, as generation of landfill gas begins 6-12 months after deposition of the waste in the landfill and usually continues for 20-50 years, once the landfill has closed.[5]

Since the implementation of gas collection in Ireland, there has been a 33 % reduction in the volume of landfill gas emitted to the atmosphere.[4] However, there is still a need to further reduce landfill gas emissions from landfill sites to comply with the Kyoto Protocol.

Landfill gas sampling at perimeter borehole wells is carried out once a month to comply with Waste Licence regulations in Ireland. Ideally, the gas concentrations for landfill gas are no higher than 1.0 % methane and 1.5 % carbon dioxide. The accepted sampling method requires that the sample be extracted from the top of the borehole well. If the gas volume is homogeneous throughout the borehole well, then extraction of a sample of various depths will still yield the same result. However, this is not always the case. When the well cap is not air tight on the top of the borehole well there is ingress from air leading to dilution of the sample under extraction. This leads to the actual diffusion gas concentration being somewhat different from what is reported. Therefore, what is accepted as a representative sample of the gas diffusing to the landfill perimeter borehole well is not, in fact, a true representation. In this paper, a preliminary study is carried out to try and better understand the dynamics of the gas in the borehole well during extraction and provide suggestions for gas sampling that is more representative of the real result.

NOVEL MONITORING DEVICE: DEVELOPMENT AND DESIGN

Data were collected using IRCel CO_2 and IRCel CH_4 infrared sensors supplied by Edinburgh Instruments Ltd., calibrated in the range 0-5 %. The readings of carbon dioxide and methane gas concentration, humidity and temperature from the borehole well are sampled and logged by the microcontroller unit and relayed to the PC base-station via a wireless Bluetooth connection.

The following figures display the Greenhouse Gas Environmental Monitoring System (G^2EMS) (Figure 1) comprised of the power source, the gas sampling unit embedded with the four sensors (Figure 2) and the communications unit. Details of the development of this system can be found in previous publications, validating the device.[6,7]

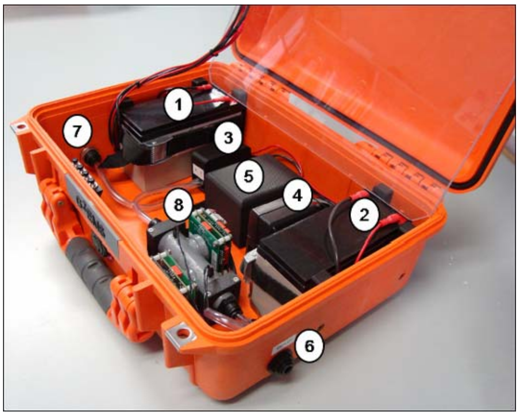

Figure 1 Internal picture of G^2EMS

1. Battery #1 (Figure 1)
2. Battery #2
3. Gas Extraction Pump
4. Communications Unit
5. Control Electronics Enclosure
6. Gas Inlet

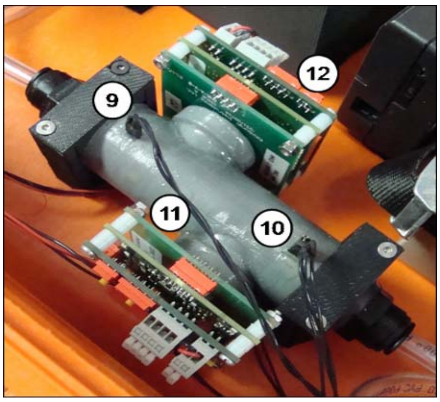

Figure 2 The sampling chamber

8. Gas Sample Chamber (Figure 2)
9. Temperature Sensor
10. Humidity Sensor
11. CH_4 IR Sensor
12. CO_2 IR Sensor

EXPERIMENTAL WORK AND FIELD VALIDATION

The G^{2}EMS unit was field validated by comparing measurements with a commercial reference device, the GA2000 Plus unit (manufactured by Geotechnical Instruments Ltd. and supplied by Commissioning Services Ltd.) These systems were connected by a length of 8 mm PVC tubing as illustrated in Figure 3 (a).

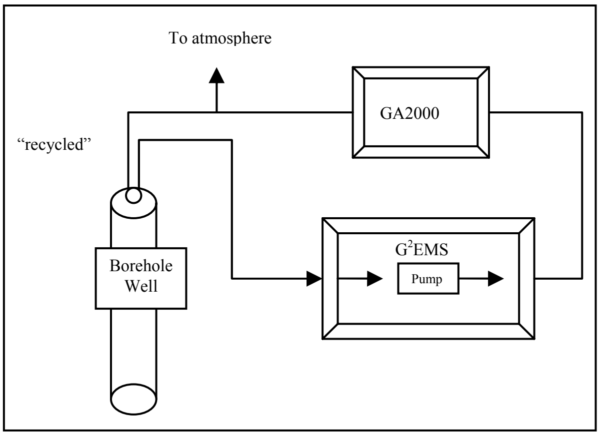

Figure 3(a) Diagram of Experimental set-up

Figure 3(b) Field Validation set-up

The pump of the G^{2}EMS unit was used to extract the sample from the borehole well and then pump the gas sample through the sampling chamber of the G^{2}EMS unit and finally the GA2000 unit (used as a reference), which remained in calibration mode, a state where its own integrated pump is inactive. Each of the sampling events took place over 3 minutes. This time interval was chosen based on the cumulative effects of the response time of the integrated sensor, the distance the gas needed to travel from the source to the sampling chamber, the time taken for the gas concentration to reach a steady-state and finally, a margin of additional time in case the concentration measured was more than expected. (An increase in concentration leads to a longer time needed for the gas concentration to reach a steady-state.)

A borehole well "cap" was constructed for these experiments, whereby samples at different depths (0.0 m, 0.5 m and 1.0 m) could be taken, as shown in Figure 4. Two different experimental procedures were implemented on the site and these will be detailed here.

Figure 4 Multiple depth cap before insertion into borehole well and in borehole well

Experimental procedure 1

Multiple samples were extracted from two borehole wells at a depth of 0.0 m and a depth of 1.0 m with a two day time interval. Samples were extracted at a depth of 0.0 m as this is the sampling depth required in the landfill site waste licence. The depth of 1.0 m was chosen as it is far enough away from the effects of dilution by air at the top of the well. Depths in excess of 1.0 m could have been chosen, but for the site used for this validation trial, a 1.0 m depth of extraction was possible for most of the borehole wells on the site, that have lesser headspaces than the two borehole wells described here. Sampling was carried out at each borehole well until a steady-state of gas concentration was reached, or until it became evident that there was no steady-state of gas concentration in the borehole well. Data points were collected at 3 second intervals using a Bluetooth connection. The exact procedure is as follows:

1. A baseline reference was taken for each unit over 3 minutes using ambient air.
2. A gas sample was extracted from the borehole well (at a depth of 0.0m or 1.0 m) and pumped through the G^2EMS unit and then the GA2000 Plus unit for 3 minutes (in calibration mode) and the sample released to atmosphere, as is the current standard.
3. The units were purged for 3 minutes using ambient air.

Experimental procedure 2

Samples of gas were extracted from two borehole wells at varying depths. The experiment followed the procedure detailed here. Data points were collected at 3 second intervals using a Bluetooth connection.

1. A baseline reference was taken for each unit over 3 minutes using ambient air.
2. A gas sample was extracted from the borehole well at a depth of 0.0 m and pumped through the G^2EMS unit and then the GA2000 Plus unit for 3 minutes (in calibration mode) and the sample released to atmosphere.
3. The units were purged for 3 minutes using ambient air.
4. Another baseline reference was taken for each unit over 3 minutes using ambient air to ensure full purging has taken place in the 3 minutes.
5. A gas sample was extracted from the borehole well at 1.0 m and pumped through the G^2EMS unit and then the GA2000 Plus unit for 3 minutes (in calibration mode). The sample was then pumped back into the borehole well at a depth of 0.0 m. This provided a closed series sampling arrangement, resulting in no loss of the extracted gas sample to atmosphere.
6. The units were again purged for 3 minutes using ambient air.
7. A baseline reference was taken for each unit over 3 minutes using ambient air.
8. A gas sample was extracted from the borehole well at 0.0 m and pumped through the G^2EMS unit and then the GA2000 Plus unit for 3 minutes (in calibration mode) and the sample released to atmosphere.
3. The units were purged for 3 minutes using ambient air.

In all, this experiment took no more than 30 minutes.

RESULTS AND DISCUSSION

In this study, the concentrations of methane gas are not discussed because on the days that this study took place, the levels were low or negligible giving no indication of how the landfill gas dynamics in the borehole well were influenced by multiple extractions of gas samples.

Borehole Well BW1

This borehole well has a headspace depth of 2.09 m and the gas samples were extracted at depths of 0.0 m and 1.0 m. A number of gas samples were extracted as described in experimental procedure 1. The data presented in Figure 5 shows that the gas concentrations were low in this borehole well at a depth of 0.0 m. The data collected using the GA2000 unit compares well with the data collected using the G^2EMS unit, validating the measurements reported by the novel unit.

Repeated sampling leads to a decrease in the gas sample concentration with no significant steady-state found. This implies that the volume of gas which has diffused to borehole well 1 is low, resulting in low concentration gas samples being extracted.

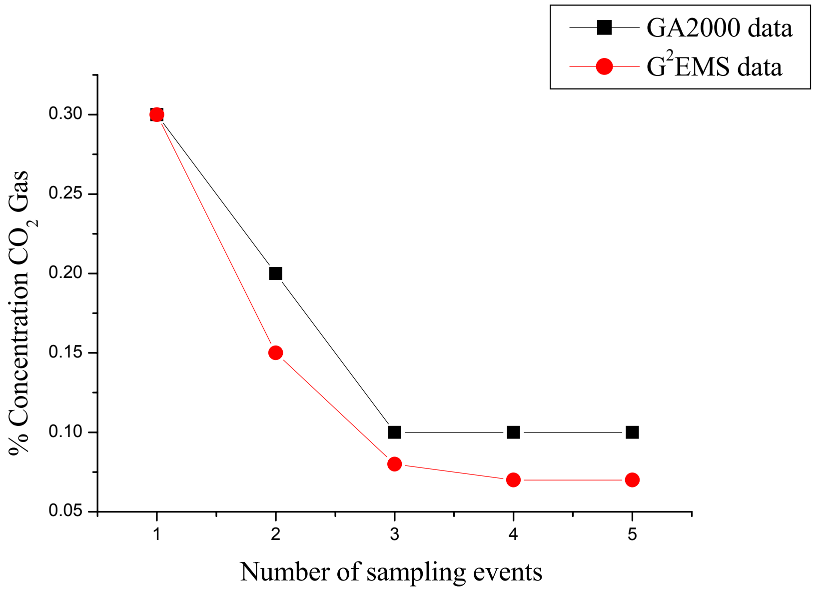

Figure 5 Borehole well data for BW1 at 0.0 m depth

Repeating experimental procedure 1 at a depth of 1.0 m gave the results displayed in Figure 6. The first sample gives a higher concentration than that seen in Figure 5 and a steady state at a concentration of *ca.* 2.75 % CO_2. Additional sampling, however, does not lead to a steady-state as the gas concentration decreases. This results from the volume of the gas present in the borehole well being low at this depth.

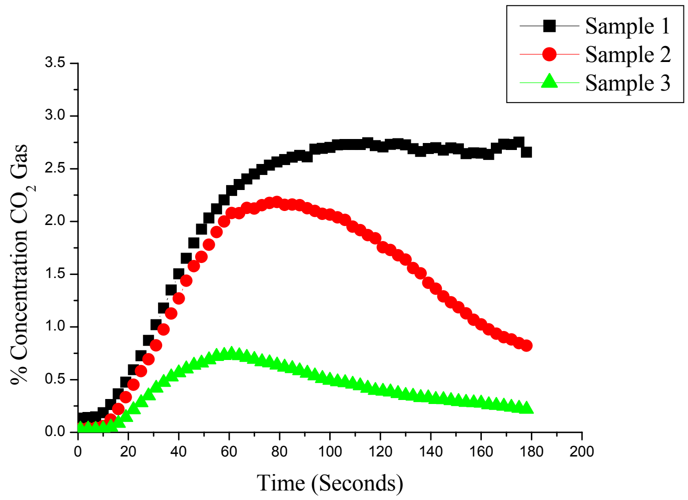

Figure 6 Data for well BW1 at 1.0 m depth

As varying the depth of the gas extraction led to a difference in gas concentration, a study following experimental procedure 2 was carried out two days later, investigating the effect of pumping the gas sample back into the borehole well on the dynamics of the gas in the well. The data resulting from this experiment are shown in Figure 7.

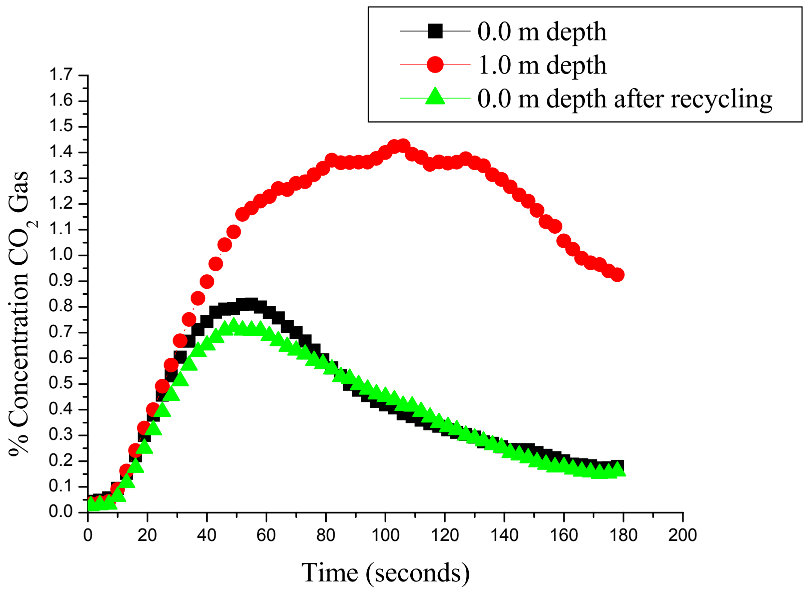

Figure 7 Borehole well BW1 after "recycling" experiment

At first glance, it seems evident that "recycling" the gas back into the borehole well does not significantly change the gas sample at 0.0 m depth in the well, as the second sample gives a similar profile to that taken 20 minutes previously. This, however, is intriguing. If the gas concentration at the top of the borehole well was not changed, then sampling the second time would provide a starting sample concentration of that seen as the end concentration of sample 1, *ca.* 0.2 % CO_2. This result was seen in the previous experiments, the results of which can be seen in Figure 6. It quickly becomes evident that one experiment will not explain this anomaly and it is only in repeated experiments using multiple borehole wells that a better understanding of the dynamics of landfill gas at the perimeter wells can begin to form.

Borehole Well BW2

This borehole well had a measured headspace of 4.46 m. The results given by the GA2000 Plus unit and the G^2EMS unit are compared in Figure 8 when gas samples were extracted at the borehole well from a depth of 0.0 m, using experimental procedure 1.

The most evident result is that the two units do not show the same concentration of CO_2 gas. They do, however, show similar trends. The units both use infrared sensors to monitor the levels of CO_2 gas. However, the GA2000 unit has sensors with the range calibrated over 0-100 %, whereas the G^2EMS unit has sensors calibrated in the gas range 0-5 %. Therefore, at these high concentrations, the G^2EMS unit is out of calibration. Consequently, in this study, the trends will be discussed, and not the actual gas concentration.

The trends in these data display a fluctuating response over consecutive sampling events. After taking 11 data points, the experiment was stopped, although stabilization of the gas concentration had still not occurred.

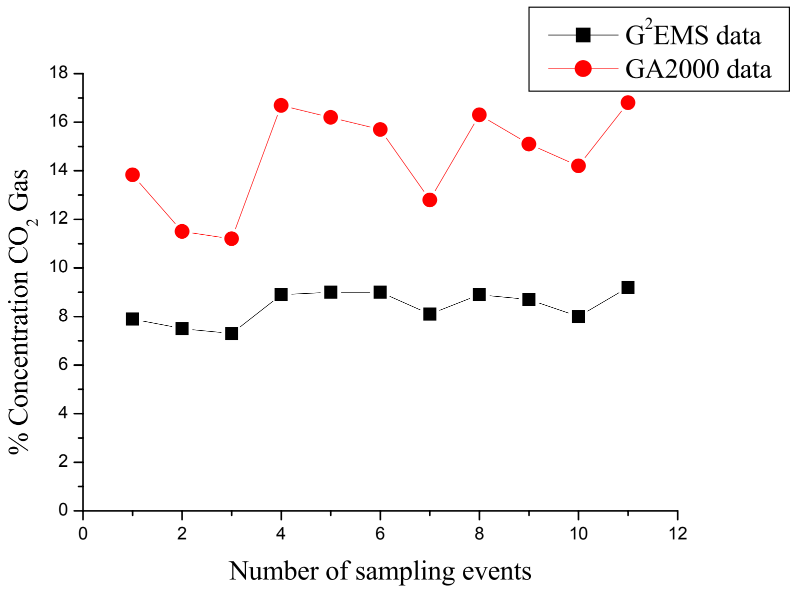

Figure 8 Borehole well BW2 data from a depth of 0.0 m

Figure 9 displays the data collected by the G^2EMS and the GA2000 Plus units from a depth of 1.0 m using experimental procedure 1. Again, the trend in both data sets is the same but the concentrations measured are different, because the sensors in the G^2EMS unit are calibrated in the range 0-5 %. The response of the sensors to gas concentration over consecutive sampling events produces a more stable response curve in comparison with that displayed in Figure 8.

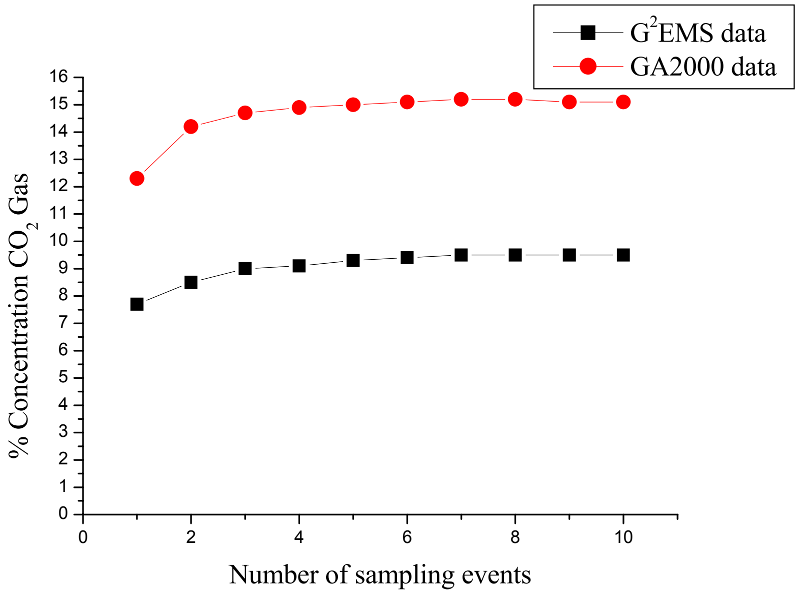

Figure 9 Average data for borehole well BW2

When the data sets presented in Figures 8 and 9 are compared, it becomes clear that at depths of 0.0 m and 1.0 m the gas concentration for CO_2 is the same, giving a value of approximately 15 % (using the GA2000 Plus value). It can be implied from this preliminary result that the gas concentrations in this borehole well are homogeneous..

Therefore, from this preliminary data, a case can be made for extracting gas from the borehole well at a depth below 0.0 m to get a more stable response from the sensors. This would limit the potential interference effects when performing gas extractions from the top of the borehole well, caused by the ingress of air and dilution of the sample. However, this type of sampling can only be implemented when the gas volume is higher.

In the next experiment, the effect on gas concentration of pumping the sampled gas back into the borehole well is investigated. The data displayed in Figure 10 represents the results of gas extractions using experimental procedure 2.

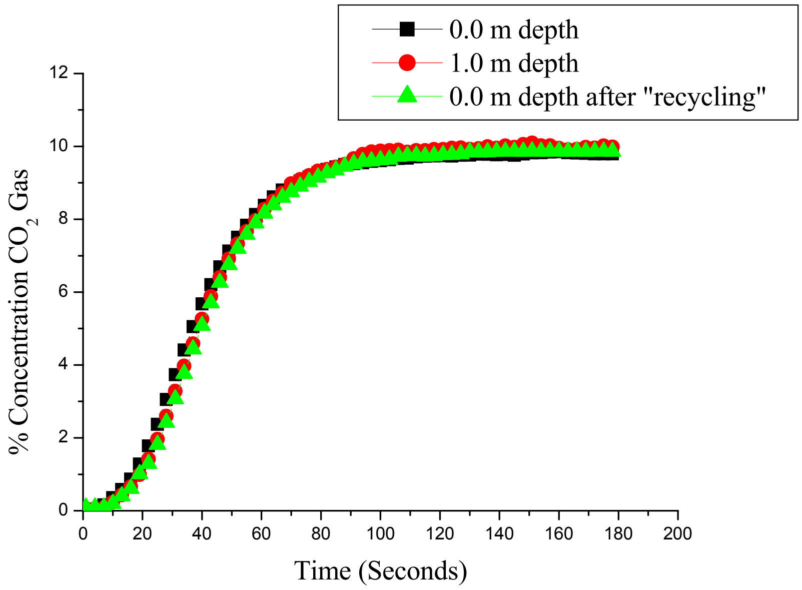

Figure 10 Data from G^2EMS Unit for BW2

From data presented in Figure 10 it is difficult to ascertain if "recycling" the gas back into the well will have an effect on the dynamics of the gas as the gas concentrations appear are the same at the 0.0 m and 1.0 m depths. Therefore, the gas in this borehole well would appear to be homogeneous, at least at the depths sampled over the time this study took place, concurring with the data presented in Figures 8 and 9.

CONCLUSIONS

The objective of this work was to carry out a preliminary study into the dynamics of the concentration of landfill gas in the borehole well. From this work, three conclusions can be drawn.

Firstly, this study has shown that there can be a difference in the concentration of the gas at different depths in the borehole well. Extracting at a lower depth can give a higher concentration of gas, as the landfill gas is not diluted with air. This would provide a more representative measurement of the actual concentration of landfill gases diffusing from the active landfill to the perimeter.

Secondly, this study has shown that when there is a large volume of landfill gas present, extracting samples at a lower well depth can lead to increased stability in sensor response and increased repeatability when multiple measurements are taken from a well within a number of hours.

Finally, it has been shown that the pumping back of the extracted sample into the borehole well may have merit as a step forward in the reduction of gas emissions to air when sampling. The studies discussed in this paper have only given preliminary data, but the work warrants further study.

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