Landfill Gas Monitoring at Borehole Wells using an Autonomous Environmental Monitoring System

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***Abstract*—**An autonomous environmental monitoring system (Smart Landfill) has been constructed for the quantitative measurement of the components of landfill gas found at borehole wells at the perimeter of landfill sites. The main components of landfill gas are the greenhouse gases, methane and carbon dioxide and have been monitored in the range 0-5 % volume. This monitoring system has not only been tested in the laboratory but has been deployed in multiple field trials and the data collected successfully compared with on-site monitors. This success shows the potential of this system for application in environments where reliable gas monitoring is crucial.

***Keywords*—**Environmental monitoring, greenhouse gas, landfill gas, sensor deployment

I. Introduction

Global warming is a recognised environmental problem in today's society affecting all citizens, irrespective of territorial boundaries. Consequently, detection and the quantitative measurement of greenhouse gas emissions is necessary as a means of predicting and monitoring climate change resulting from the production and release of fugitive greenhouse gas emissions in the present day. This paper describes the successful trialling of a recently developed monitoring system for the greenhouse gases - carbon dioxide and methane. Validation of the system was carried out through monitoring of landfill gas at perimeter borehole wells, ensuring the presence of both gases at varying concentrations.

Monitoring of methane emissions, in addition to carbon dioxide emissions is important because of its global warming potential (GWP). The GWP of methane is 21 over 100 years and 56 over 20 years, compared with carbon dioxide which is normalised to 1 in both cases [1]. Therefore, the reduction of methane gas emissions to the atmosphere through incidental releases should be a key goal. The main methods of methane emission reduction on landfill sites is through gas flaring or the use of landfill gas as a fuel on larger landfill sites, exploiting its flammable nature [2]. Since gas collection was implemented in Ireland, there has been a 33 % reduction in the volume of landfill gas emitted to the atmosphere [2]. Despite this positive result, monitoring of gas migration to the perimeter borehole wells still needs to be regularly and reliably monitored. This is where the Smart Landfill system finds its application.

The Smart Landfill system described in this paper marries commercially available infrared gas sensor technology with wireless communications to monitor methane and carbon dioxide gases at perimeter borehole wells on landfill sites. The waste licence granted to these landfill sites by the EPA recommends that the methane levels remain below 1 % volume (20 % of methane LEL) and below 1.5 % for carbon dioxide [3]. To facilitate the detection of these levels, the target gas range of the system is 0-5 % volume for both methane gas and carbon dioxide gas.

The ultimate goal of this research is to develop a completely autonomous monitoring system, meaning there is no need for personnel to spend many hours taking readings using handheld equipment at each of the borehole wells around the perimeter. This final system will be capable of performing measurements independently, or as instructed, and the system will be left at the borehole well, so transport of the system is unnecessary. Results will be available in real-time once the sampling cycle has been completed, making it easier for data comparison and modelling. Using this data, an operator can decide if the collection of more data sets is needed where a potential problem (e.g. a blocked gas extraction pipe) has been flagged.

II. Landfill Gas Generation, Migration and Monitoring

Landfill gas is generated by the decomposition of biodegradable waste in an anaerobic environment [4]. The main components are carbon dioxide and methane, with trace amounts of volatile organic compounds which are known to cause the malodour of fresh waste.

These gases are formed when acetate is broken down to form methane or carbon dioxide in the presence of hydrogen. (See Eqt. 1)

Eqt. 1 $$CH_3COO^- + H^+ \rightarrow CH_4 + CO_2$$

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Some of the methane gas is initially oxidised to methanol and subsequently to carbon dioxide and water by methanogenic bacteria in the soil. (See Eqt. 2)[5]

Eqt. 2 $$2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$$

The rate of production of landfill gas depends on a number of factors including the amount of moisture present (needed to promote the conversion of waste to methane and carbon dioxide) [6], soil type and pH [7], age of the landfill [4] and effectiveness of gas extraction to the flare [6]. Similarly, the amount of gas migration and emission can be affected by changes in atmospheric pressure [8] and moisture content in soil [9].

At present, there are 81 licensed sites in Ireland, 36 of which are active [2]. Landfill gas production is known to be unpredictable in closed sites, with generation of landfill gas beginning 6-12 months after deposition of the waste in the landfill and continuing for 20-50 years, once the landfill has closed [4]. In some cases, landfill gas production can continue for hundreds of years after site closure, depending on the rate of waste degradation, the type of deposited waste and the rate of landfill gas production [3]. Therefore, continued monitoring of gas emissions are vital, even on inactive sites, particularly those located in the vicinity of commercial and residential areas.

To combat the uncontrolled release of methane and carbon dioxide emissions into the atmosphere, landfill sites are designed with gas extraction systems. Predominantly, landfill sites in Ireland are small and the bulk of landfill gas produced can be effectively flared off. Where large volumes of landfill gas are produced, it is used to generate power (when the composition is >50 % methane) [3], [10]. Reduction of these emissions ensures that there is little potential for these gases to build up, causing harm on or off the landfill site.

Collection wells (borehole wells) have been installed around the perimeter of the landfill site to monitor migration of landfill gas from the site. In Ireland, these wells are sampled once a month using commercially available handheld infrared devices and the results communicated to the Environmental Protection Agency, Ireland [11].

III. INFRARED SENSORS AND CALIBRATION

Data were collected using IRCel CO_2 and IRCel CH_4 infrared sensors supplied by Edinburgh Instruments Ltd. The calibration data are reliable and reproducible, as shown in Fig 1.

The sensors were calibrated in triplicate against the target gas in the range 0-5 % with a nitrogen gas balance. The standard deviation in the range 0-1 % for carbon dioxide is 1.3 %, while the standard deviation over the range 0-5 % for carbon dioxide is 1.9 %. Similar data were collected for the IRCel CH_4 sensor.

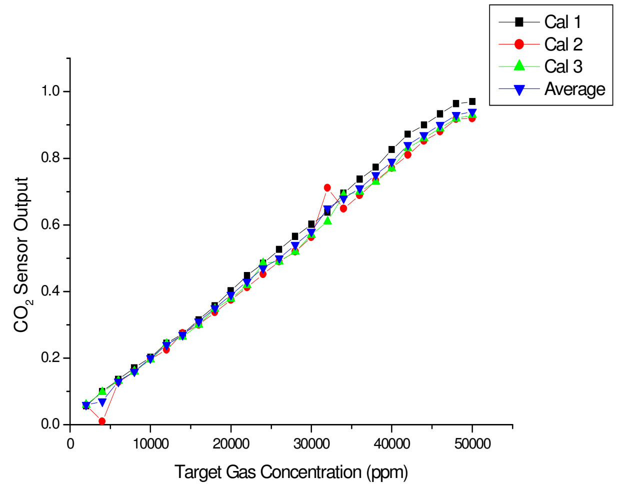


Fig. 1 Calibration data for IRCel CO_2 sensor

IV. THE MONITORING SYSTEM

There are numerous considerations when designing any monitoring system which will be field deployed for an extended period of time. These considerations include storage and retrieval of the sample data from the sensors, power consumption of the system, the robustness of the system and the effectiveness and reliability of the sampling used to retrieve samples of the target gas.

The Adaptive Sensors Group is experienced in designing, building and deploying autonomous field deployable systems [12-14]. Accordingly, aspects, of this system have used earlier work in the area as a reference, e.g., the autonomous phosphate system [15].

(a) Data storage and retrieval

The measurements of carbon dioxide and methane gas concentration, humidity and temperature from the borehole well (see Fig. 2) are, at present, read using Bluetooth wireless technology. Data are recorded using Hyperterminal as they stream in real-time during sampling. In the next generation of this unit, the data will be copied to a flash memory chip and then, using GSM communications, a segment of this data will be delivered via text message to the programmed recipient. If there is an interruption in the signal, the data are still stored on the flash memory chip, meaning that data integrity is still maintained.

Fig. 2 A sample of landfill gas being pumped from a borehole well at the perimeter of an active landfill site

(b) Power consumption

The power consumption of the Smart Landfill system is dependent on a number of factors, including the number of sensors collecting data, the frequency of sampling, the capacity of the battery used and the applicability of renewable power scavenging techniques, such as solar panels.

The current consumption of each infrared sensor is approximately 0.20 A over 5 V [16]. A lead acid battery with a capacity of 7 Ah at 12 V is used, giving the system enough power to operate continuously for up to 17 hours. As one sample cycle takes less than one hour and only one sample cycle is required per day, two of these batteries give the system a deployment time of over one months duration.

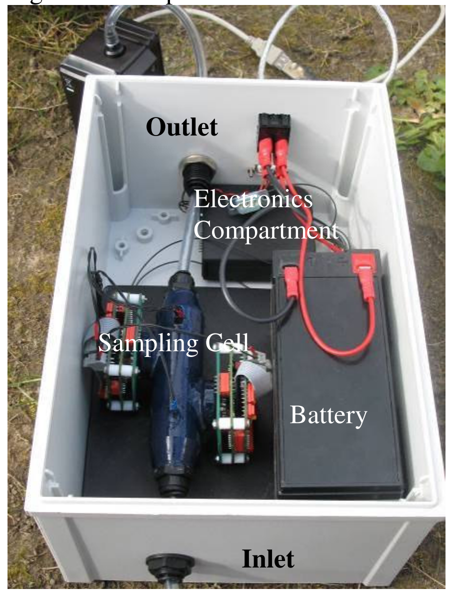
(c) Housing

The Smart Landfill system is housed in a robust transparent polycarbonate casing (manufactured by Fibox and supplied by Radionics, product code 509-3322), which is water tight and shatter resistant, as displayed in Fig. 3. Inlet and outlet fittings (8 mm) are located on opposing faces of the casing. The system power switch and the RS232 connection port for data acquisition are mounted externally for easy access by the operator.

(d) Components

The Smart Landfill system, as displayed in Fig. 3, comprises the battery, the gas sampling unit embedded with four sensors and the electronics compartment. For this prototype system, the data are communicated via an RS232 cable fitted to the outside of the housing and/or also via Bluetooth wireless communication. Data are saved onto a Dell Notebook using Hyperterminal.

Fig. 3 Internal picture of the Smart Landfill Unit

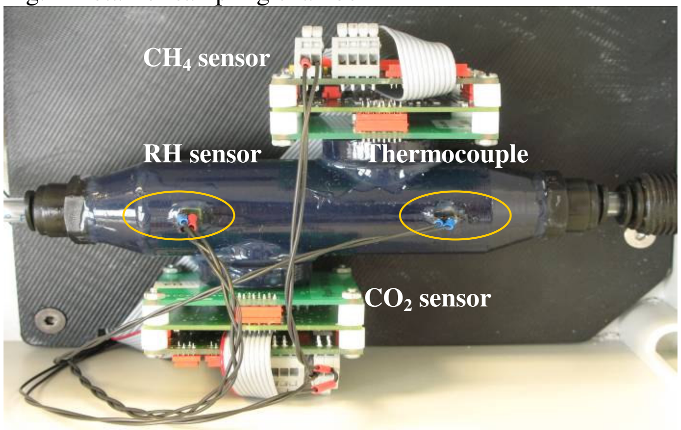


(e) Sampling Chamber

The sampling chamber is displayed in Fig. 4, with four sensors embedded into the chamber. These sensors include one humidity sensor and a thermistor for temperature measurements, and two infrared sensors – one for carbon dioxide gas and one for methane gas measurement. The gas sample is extracted from the borehole well using an air pump at a rate of 0.6 L/min. The gas pump (AirLite Sampler Model 110-100 distributed by SKC) is housed outside the main unit and the gas is vented to ambient air, after sampling.

The sampling unit, with an internal volume of 45 cm^3 was fabricated in ABS plastic using a 3-D rapid prototyping process (Dimension SST 768). Pneumatic hose fittings (8 mm) at either end of the sampling chamber allow connection to the borehole well outlet and the gas sampling pump. Openings of appropriate size accepted four rigidly mounted sensors. Exposed pins allow connection of the sensors to the microcontroller board. The exterior of the chamber was sealed using silicone spray (supplied by Radionics, product code 101-6343). Trials measuring a constant nitrogen flow using manual flowmeters showed that the chamber could maintain an internal pressure of 1 bar. This ensured that sample gas drawn by the pump was not diluted by leaks in the unit.

Fig. 4 Detail of sampling chamber



V. VALIDATION OF THE SMART LANDFILL SYSTEM

This system has been used successfully in a number of field trials; two of which are profiled in this paper, displayed in Figure 5. The active landfill site chosen is in North East Ireland and the data sets discussed were gathered in the months of February and March 2008.

Figure 5 Smart Landfill Unit #1 gathering data on a field trial

In the field trials, the data collected by the Smart Landfill unit were compared with data obtained using the GA2000 unit, produced by Geotechnical Instruments Ltd. calibrated on-site. This unit is a handheld infrared landfill gas monitor with a range of 40 % volume of carbon dioxide and 60 % volume of methane. In all, data were collected at 10 borehole wells over the two month period and the data are reported in Table 1. On initial inspection of the data, it is evident that the trends are similar between the Smart Landfill Unit and the GA2000 unit, which is a positive result.

The data collected at the borehole wells B5(Feb) and B7(March) have carbon dioxide measurements beyond the calibrated range of the sensor, therefore, the results cannot be relied upon. However, it is encouraging that the Smart Landfill sensor can show that the concentration of gas was out of the calibrated range and can recover quickly, without any damage to the sensor. Landfill gas production is unpredictable, therefore, although one expects to find low landfill gas concentrations (<5 % volume), this is not always the case.

Looking critically at all the collected data, the trends between the two systems are similar, but not similar enough for a direct comparison. The data collected at these initial trials prove that the Smart Landfill system has potential as a unit capable of detection and quantitative measurement of greenhouse gases, but that the sampling method is not, at present, superior to the GA2000 unit.

There are two main reasons why data collected by the GA2000 unit and the Smart Landfill system are different. There is a difference in calibration of the GA2000 unit and the Smart Landfill Unit. The GA2000 takes a baseline of ambient air at each borehole well and is calibrated against a standard of 40:60 CO_2:CH_4 gas. The Smart Landfill Unit is calibrated in the laboratory against nitrogen and against a standard mixture of 95:5 nitrogen:target gas. This inconsistency of baseline and sensor calibration will be rectified in the next phase of the project, whereby, the sensors will be calibrated on-site and the ambient air baseline taken at each sampling site.

The second and more significant reason why the results are different is rooted in the unpredictability of landfill gas production and migration. Multiple samplings of the same borehole well often produce different readings. Where low gas readings occur, sometimes the built-up gas disappears, leading the second sampling to collect a gas reading of zero. Where high concentrations of landfill gas occur, additional sampling can promote more gas to migrate to the perimeter of the site. Therefore, it is difficult to record the same result with two different systems at the same time and at the same borehole well, without the same gas sample being used.

In the case of the February field trial (data collected at wells B2-B6 (Feb)), the Smart Landfill readings tend to be 0.5-0.6 % lower than the GA2000 readings. In all readings, the GA2000 unit collected data first. But in the March field trial, the Smart Landfill Unit readings are significantly higher when this unit sampled the borehole well first (B2, B3 and B8 (March)). The authors are confident that with further development of the unit and with more data collected over multiple trials, these issues can be better explained and the responding modifications will make the unit stronger as a tool for greenhouse gas detection and measurement in areas of interest.

VI. CONCLUSIONS

There is a need in the market for an autonomous field deployable system capable of detecting and quantifying concentrations of greenhouse gas emissions at sites of interest. The authors have designed, built and successfully field deployed such a system, capable of detecting and measuring concentrations of carbon dioxide gas and methane gas present in borehole wells at the perimeter of landfill sites. These data, sampled in real-time, can be communicated to a base-station on-site or off-site using wireless communications.

This unit has an added advantage, in that detection and measurement of the gas sample can be carried out without any degradation of the sample. Infrared detection is reagentless and samples could be collected for additional off-site analysis, if additional verification of the monitoring system is needed.

The prototype of this system has proven successful and, although, the field trials have revealed areas that need more development, this paper has demonstrated that a system of this design can be effective in the relay of valuable real-time information on greenhouse gas concentration from a site of interest.

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Table 1 Field Trial data for the Smart Landfill system

Borehole well	CO_2 GA2000	Sensor Conc CO_2	CH_4 GA2000	Sensor Conc CH_4
B2 (Feb)	4.2	3.7	0.0	0.0
B3 (Feb)	1.3	0.8	0.0	0.0
B5 (Feb)	11.2	>5.0	3.9	3.3
B6 (Feb)	0.1	0.1	0.0	0.0
B2 (March)	3.5	4.5	0.0	0.0
B3 (March)	1.8	2.7	0.0	0.0
B4 (March)	2.6	2.4	0.1	0.0
B6 (March)	0.0	0.0	0.0	0.0
B7 (March)	5.8	>5.0	0.0	0.0
B8 (March)	2.5	2.8	0.7	0.5