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# Quantification of $CH_4$ and $CO_2$ Concentrations at Different Depthsin a Landfill Site and Two Peat Soils

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**Abstract:** The variability of $CH_4$ and $CO_2$ concentrations with depth has been determined in a landfill site and two peat soils by means of an In-borehole gas monitor, the GasClam. Four boreholes of different depths were monitored for $CH_4$ and $CO_2$ concentrations and their average over the monitoring period per borehole (depth) was determined. Most of the results in the monitored sites show that whilst $CH_4$ concentrations increased with depth, $CO_2$ concentrations showed an inverse relationship with depth. For example, at site 3, in borehole 2 (9m deep), $CH_4$ and $CO_2$ had concentrations of 26.72 and 3.10% respectively whilst in borehole 4(8m deep), they had concentrations of 22.43 and 4.94% respectively. Whilst the same was the case in site 2, it was only in site 1 where variations in borehole depth did not result in remarkable changes in $CH_4$ and $CO_2$ concentrations. This suggests that the findings of Holden (2005) are limited to gas availability which is a function of the rate of gas production in the site. The behaviour of the gases in Site 1 might not be unconnected to its highly eroded nature which creates more room for gas emission.

**Key words:** GasClam · Borehole · Ground-Gas · Climate Change · Gas Production Rate

## INTRODUCTION

Ground-gas concentration such as that of $CH_4$ and $CO_2$ has been shown to vary in concentration with depth in peat soil [1]. Holden, [2] specifically found $CH_4$ concentration to increase with depth whilst $CO_2$concentration showed reverse behaviour with depth. He however did not prove whether this is also applicable to other soils such as landfills since the processes taking place in peat may not be the same for other soil types.

Moreover, since changing climate or management can alter the processes taking place in peat land [3, 4]. It is possible that the findings of Joseph Holden [5] might have changed especially given that it is more than a decade since this research was conducted. It was sequel to that this research was conducted to determine whether his findings are still the same contemporarily. If the later validates the former, there will also be a requirement to verifywhether they are the same for different sites.

## MATERIALS AND METHODS

TheGasClam [4-9] was designed to operate remotely; specifically in 50 mm ID monitoring wells. It monitors and records the following parameters: $CH_4$, $CO_2$, $O_2$, CO, $H_2S$ and VOCs, atmospheric pressure, borehole pressure, pressure differential, temperature and water level [10-13]. It is made from stainless steel and is also intrinsically safe (rated to ATEX/BASEEFA Standards). It is environmentally sealed and has ingress protection rated IP-68. The GasClam is battery operated and can be powered for up to three months whilst operating on an hourly sampling frequency. Target applications for the Gasclam ground gas monitor include landfill for long term profiling, brownfield sites for development issues, monitoring for coal mine fires, leakage of crude/petroleum, solvent storage and filling stations, oil refineries for local compliance/regulation and for below ground carbon capture and storage monitoring regime.

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Gasclam units were installed to monitor ground-gas continuously on hourly sampling intervals for different periods in a landfill and two peat sites. The investigated sites are located in United Kingdom and are described below. The in-situ continuous data of $CH_4$ and $CO_2$ concentration were downloaded from the Gasclam and their average calculated. The data were subsequently analysed to determine their variability with depth.

**Site Description:** Site 1an upland peat which has eroded and uneroded sub-sites is located at the Crowden Great Brook, near Manchester, UK. It has a total surface area of $7km^2$ [6] with a mound topography and belongs to the Peak District National Park. All the waters of the catchment are collected by stream systems which originate from Black Hill into Torside reservoir [7]. Gritstone and Shale are dominant rocks in this place while moorlands and bogs are the dominant peat lands and the depth of these peats is up to four meters from the surface [8]. In the Peak District, about 27% of the moorland has been degraded due to air pollution from industrial activity, overgrazing, excessive walking and climate change [9]. The peat has developed from decay of sphagnum moss over thousands of years. The eroded sub-site has a greater surface area of bare peat compared to the uneroded. Although greenhouse gases from the 2 sub-sites were supposed to be monitored for the purpose of comparison, it is only the uneroded site (shallow and deep boreholes) that was investigated. A comparison of gas concentration in the 2 boreholes would help to determine which of old (deep borehole) and new (shallow borehole) peats produces more of ground-gas [10].

Site 2 is a lowland peatwhich is partly restored and partly unrestored peat soil and forms part of a much larger peatland located in Astley, Salford, UK. This site has been subject to a large scale block-cut peat extraction. The resultant loss of surface vegetation and the drainage undertaken for this peat extraction, combined with the improvement and drainage of adjacent farmland and the construction of railway along southern (restored) part of the site resulted in a modified bog habitat that lacked many of the wetland species. Nonetheless, the areas was designated a Site of Biological Importance (SBI) in 1980, mainly due to a small population of a nightjar (Caprimulgus europaeus) that were present at the time. Subsequent losses of surface vegetation through peat milling resulted in reductions in the size of the SBI, until 1987 when it was considered to be too small to qualify for this status. The northern section (unrestored part) has not been worked since 2001. The need to characterise ground-gas concentrations from this site arose due to fear by the local council that it might be emitting huge amount of greenhouse gas into the atmosphere each time it is exposed by cutting. In this site, 2 boreholes (shallow and deep) were monitored in the restored sub-site and 2 boreholes (shallow and deep) in the unrestored counterpart. This is in order to determine the difference in the amount of greenhouse gas released by the sub-sites and also to verify the effect of borehole depth on the variability of greenhouse gas released by the boreholes.

Site 3 is a former ‘brickworks and associated clay pits’ which became a landfill site in the 1940s, for the dumping of household, commercial and industrial waste materials. It ceased to be used as landfill in about 1975. Residential properties were built on the site during the 1970s. During the late 1990s, gas was found to be leaking into some of the properties [11]. In 1999, a 'venting trench' was built to prevent gas leaking into the houses. Although it helped, the problem was not completely resolved. But excavations within the last few months have established some of the properties are on top of tipped material and it was formally declared 'contaminated land’. Physical site investigation works have confirmed the presence of such wastes in the eastern portion of the tip, although limited information is available for the remainder of the landfill area. A further landfill site comprising the infilled section of an abandoned railway cutting (southern strip) is situated immediately to the south of the landfill Site and is reported to have been filled with inert wastes only [12].

Landfill and peat sites were chosen for this study because they are important sources of hazardous ground-gases especially methane and carbon dioxides. For example methane ($CH_4$: 55–60% v/v) and carbon dioxide ($CO_2$: 40–45% v/v) are the major gases produced by biodegradation of land fill wastes [13]. Scheutz *et al.* [10] noted that the biodegradable organic material in waste includes paper, animal and vegetable matter and garden waste.

## RESULTS AND DISCUSSION

The range and average concentrations of $CH_4$ and $CO_2$ in boreholes at sites 3-1 are represented by Figs. 1-3 respectively . The depths (cm) of boreholes in the 3 sites were considered in order to determine the variation of ground-gas concentration with depth. It was the average concentrations of the gases that were compared with the depths of the boreholes in the investigated sites.

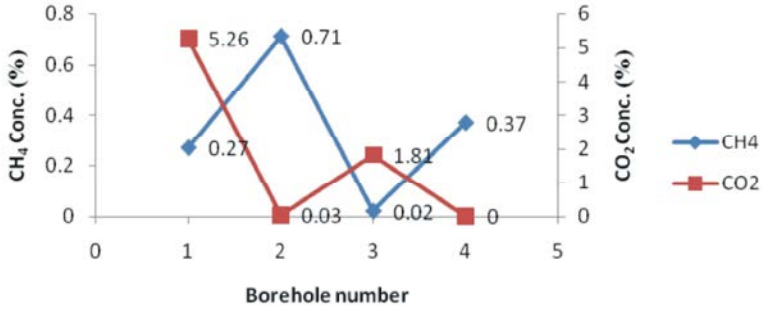


Fig. 1: The range and average concentrations of $CH_4$ and $CO_2$ in boreholes at site 3. The depths of boreholes 1-4 are 80cm, 130cm, 80cm and 170cm respectively

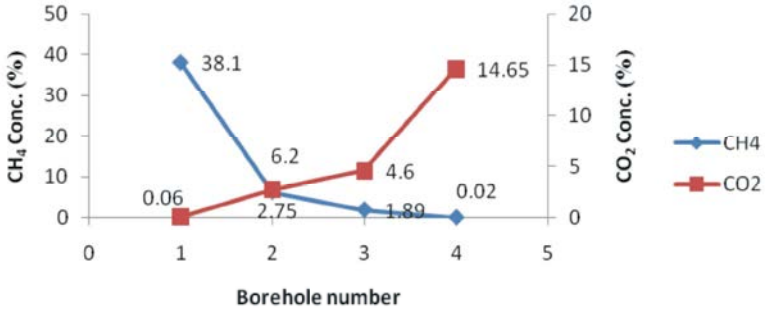


Fig. 2: The average concentrations of $CH_4$ and $CO_2$ in boreholes at site 2. The depths of boreholes 1-4 are 180cm, 120cm, 100cm and 80cm respectively

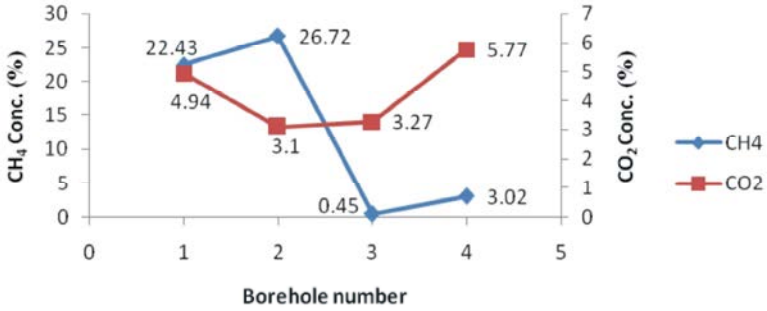


Fig. 3: The average concentrations of $CH_4$ and $CO_2$ in boreholes at site 1. The depths of boreholes 1-4 are 8.30m, 9m, 7m and 7.30m respectively

Whilst the datasets used to calculate the average concentrations of $CH_4$ and $CO_2$ in site 1 were collected from September 2010 to June 2011, that of sites 2 and 3 were collected from January 2011 to November 2011 and February 2012 to September 2012 respectively.

As can be observed from site 1, the average concentrations of $CH_4$ and $CO_2$ are in the order of borehole 2>borehole 4>borehole 1>borehole 3 and borehole 1>borehole 3>borehole 2>borehole 4 respectively (Fig. 1), whilst in site 2, they are both in order of 1>borehole 2>borehole 3>borehole 4 and 4>borehole 3>borehole 2>borehole 1 respectively for $CH_4$ and $CO_2$ (Fig. 2). In site 3, their average concentrations are in the order of borehole 2>borehole 1>borehole 4>borehole 3 and 4>borehole 1>borehole 3>borehole 2 for $CH_4$ and $CO_2$ respectively. The highest average concentrations of $CH_4$ and $CO_2$ in site 1 are 26.72 and 5.77% respectively whilst in site 2, $CH_4$ and $CO_2$ had highest average concentrations of 38.10 and 14.65% respectively. In site 3, it is 0.71 and 5.26% for $CH_4$ and $CO_2$ respectively. The high concentrations of ground-gas recorded in these sites suggest that remediation was not effective.

**Comparison of Concentration with Depth:** The concentrations of the gases at different depths depend on their availability - which is a function of their rate of

production in the site. For example, in site 1, boreholes 1 and 3 which are both 80cm deep, had average $CH_4$ concentrations of 0.27and 0.02% respectively and average $CO_2$ concentrations of 5.26 and 1.81% respectively. The variability in gas concentration even at the same depth is dependent on their availability in the two different boreholes.

However, the average concentrations of $CH_4$ and $CO_2$ in boreholes 2 and 4 which are 113cm and 170cm deep respectively show a clearer picture of their variability with depth. For example, the concentration of $CH_4$ at the depth of 130cm (0.71%) is more than 23 times the average concentration of $CO_2$ (0.03%) at the same depth. At the depth of 170cm (borehole 4), while an average $CH_4$ concentration of 0.37% was observed, it was 0% concentration of $CO_2$ that was recorded. This validates the findings of Holden [1] that whilst CH4 concentration increases with depth, that of $CO_2$ actually shows a reverse relationship with depth. However, the concentration of the gases is dependent on the rate of gas production in the borehole.

The findings of Holden agree more explicitly with the relationships between the average concentrations of the gases with depth in site 2 (Figure 2). It shows that the highest concentration of $CH_4$ (38.1%) was observed at borehole 1 (180cm) whilst its lowest concentration of 0.02% was recorded in borehole 4 (80cm). The reverse is the case of $CO_2$ with the highest concentration in of 14.65% in borehole 4 (80cm) and the lowest concentration of 0.06% in borehole 1 (180cm). This further validates the findings of Holden [1].

In Site 3; at the depth of 9m (borehole 2), the highest average concentration of $CH_4$(26.72%) was recorded during which $CO_2$ concentration was 3.10%. However, at the depth of 8.30m, CH4 concentration dropped by 4.29 to 22.43% whilst $CO_2$ gained 1.84 to 4.94% signalling an inverse relationship with depth. At the depth of 7m (borehole 3) $CH_4$ concentration crashed to 0.45% while $CO_2$ concentration further increased to 3.27%. When the depth was raised to 7.30m, $CH_4$ started recovering during which it recorded average concentration of 3.02% with $CO_2$ concentration of 5.77%. Although it can be deduced that $CH_4$ and $CO_2$ concentrations increase and decrease respectively with depth, the concentration of the gases recorded at each depth depends on gas availability.

## CONCLUSION

In general, more $CH_4$ concentrations are produced in deep boreholes than shallow counterparts whilst the reverse is the case for $CO_2$ concentrations. This observation validates the findings of Holden [1] that more $CH_4$ than $CO_2$ concentration is produced under anaerobic condition. Also, more ground-gas is produced in restored sub-site (boreholes 1 and 2) than in unrestored sub-site (boreholes 3 and 4) of site 2. Although no water table data were collected, high ground-gas concentration detected in the restored sub-site suggests that the remedial flooding may have raised the water table.

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**Conflict of Interest:** LNote that there is no conflict of interest whatsoever.

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