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The utility of concentration duration curve in CH_4 and CO_2 risk assessment

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A B S T R A C T

Current CH_4 and CO_2 risk assessment of comparing the single occurrence of worst-case concentration with trigger values of 5% and 1% respectively is often of low resolution but could be improved by the application of the concept of Concentration Duration Curve (CDC). With the aid of the Gasclam (In-borehole continuous gas monitor), four sites were monitored for CH_4 and CO_2 concentrations, and the time-series datasets used to construct CDC. The result shows that a 5% CH_4 concentration is exceeded for 17, 41, 0, and 0% of the monitoring period in sites 1-4 respectively, whilst a 1% CO_2 concentration was exceeded for 75, 75.5, 100, and 93% of the time in sites 1-4 respectively. The recorded worst case CH_4 concentration are 11.5, 22.1, 2.7, and 1.56% in sites 1-4 respectively while that of CO_2 concentration are 8.2, 15.5, 3.3, and 6.71% in sites 1-4 respectively This implies that treating risk in terms of a single occurrence of the worst-case ground-gas concentration rather than any sort of time-weighted function can be defective. While the concept of CDC can be useful in improving risk assessment due to CH_4 and CO_2, the worst-case ground-gas concentration may not occur during the monitoring period, therefore prediction is required. To predict the worst-case ground-gases concentration requires an understanding of the processes responsible for controlling gas concentration.

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1. Introduction

Methane (CH_4) and carbon dioxide (CO_2) are hazardous ground gases. They are often among the most frequently detected contaminants in soil and groundwater around landfills and brownfield sites over the world (West et al., 1995). The redevelopment of these contaminated sites necessitated by increasing demand for housing (for example, in the UK) and change in government policies introduces the need for effective risk assessment (NHBC, 2008).

As part of effective risk assessment, the hazards (such as an explosion) present in the environment (built or natural) are identified and then evaluated to determine their probability of occurrence (risk) (EA, 2004). The definition of a representative ground-gas concentration depends on the risk. When the main risk is chronic GHG emissions (global climate change) then the representative concentration is a relatively long-term average. But assessment for an acute explosion risk is built around the worst-case concentration; therefore, its only requirement of monitoring at present is to aid in detecting or predicting this.

Ground-gas risk assessment relies largely on the determination of the worst-case ground-gas concentration–the maximum value recorded (Boult et al., 2011). The guidance suggested that risk should be treated in terms of a single occurrence of the worst-case ground-gas concentration rather than any sort of time-weighted function (Boult et al., 2011). Therefore, a worst-case is assumed to be the same whether it remained constant during the monitoring period or occurred only for a certain % of the monitoring time.

Presently, whether the risk is acceptable or not is based on the comparison of worst-case ground-gas concentration to the maximum permissible

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concentration of ground-gases (Gas Screening Values) in the environment (Boyle and Witherington, 2007). For example, in the United Kingdom, the use of Gas Screening Values (also known as the threshold or trigger value) of 5% v/v of CH_4 and 1% v/v of CO_2 is recommended (Morris et al., 2008; Wilson et al., 2008; Sladen et al., 2001).

This approach to ground-gas monitoring is considered by many researchers to be exceedingly conservative (Wilson et al., 2008; Sladen et al., 2001). This is because the approach is often ineffective for determining the risk due to ground-gas concentration. Both Tillman and Weaver (2005) and Siegrist (2003) have noted that this approach of determining risk from the worst-case ground-gas concentration is insufficient to be used as a standard for planning contaminated land redevelopment. Moreover, concentration may not be a consistent indicator of risk as processes of migration, and generation may cause it to be variable (Sladen et al., 2001).

It is, therefore, not enough to only compare the worst-case concentration to the GSV to determine whether a risk is acceptable. It is also necessary to use as much other information as possible concerning the site and processes of ground-gas generation and migration. Such data could include site-specific information such as site history (age of the site, the design capacity of the site, amount of waste in place in the site, and the type of waste buried in the site), and site geology (fissures, bedding, faults and joints within consolidated strata) (Boyle and Witherington, 2007). Also crucial is the information about the general processes taking place on the site which is learned from other sites. Such information includes the methane generation rate, and the potential methane generation capacity (Nwachukwu and Anonye, 2013). This information is used to produce what is known as a Conceptual Site Model (CSM) (NHBC, 2008; EA, 2004; Boult et al., 2011). The CSM can replace the reliance on comparison to a GSV and can also be used to give a better indicator of worst-case gas concentration.

Requirements for the construction of a CSM include the collection of site-specific concentration data. Typically, the data is often of low resolution (insufficient quality) to contribute to the construction of CSM.

2. Methodology

From the above, it is apparent that worst-case ground-gas measurement is of low temporal resolution. A new instrument, Gasclam (Morris et al., 2008), which is designed to measure ground-gas concentrations at the high-temporal resolution, is recently available. In this work, the Gasclam was deployed in four contaminated sites and collected datasets used to determine whether:

I. Concentration duration curve obtained by high-resolution ground-gas concentration measurement can reduce the uncertainty in ground-gas risk assessment.
II. High-temporal resolution ground-gas concentration data may help to improve the ability to determine the worst-case ground-gas concentration. Worst-case ground-gas concentration could be detected by monitoring. The ability to monitor ground-gas concentration at high temporal resolution could allow recognition of any inconsistency between sampling frequency and concentration variation (Morris et al., 2008; Young, 1992; McHugh and Nickels, 2007). This could be achieved by allowing samples to be collected at a temporal resolution higher than the variability of gas concentration thereby allowing optimum sampling frequency to be identified (Morris et al., 2008; Todman, 2008). With optimum sampling frequency; the worst case could better be detected during the monitoring period.

3. Results and discussion

3.1. Ground-gas concentration duration curve

With time-series data, a meaningful summary of concentration measurement can be generated. At present, the only meaningful summary is whether a borehole ever had a concentration measurement greater than 5% methane and 1% carbon dioxide (Morris et al., 2008; Wilson et al., 2008; Sladen et al., 2001). In these cases, (sites 1–4), the use of low-frequency sampling to identify the worst case will be misleading. For example, the 'worst case' has been detected by hourly sampling over the monitoring periods in each of the datasets (Fig. 1); as CH_4 and CO_2 concentrations were shown to exceed 5% and 1% respectively for some time. Weekly to monthly sampling is likely to fail to coincide with the 'worst case' thereby give a false negative.

By applying the concept of hydrological flow duration curve, one can generate a concentration duration curve that tells what the worst-case concentration is. Fig. 2 shows the Concentration Duration Curve that resulted from the time series data from sites 1 to 4 (Fig. 1). As can be observed in Fig. 2, the continuous data Concentration Duration Curve indicates that a 5% CH_4 concentration is exceeded for 17, 41, 0, and 0% of the monitoring period in sites 1-4 respectively, whilst a 1% CO_2 concentration was exceeded for 75, 75.5, 100, and 93% of the time in sites 1-4 respectively. Fig. 1 also shows the 'worst case' (that is, the maximum recorded) CH_4 concentration in sites 1-4 to be: 11.5, 22.1, 2.7, and 1.56% respectively; and that of CO_2 concentration as 8.2, 15.5, 3.3, and 6.71% in sites 1-4 respectively.

The worst-case concentrations resulting from high-frequency monitoring occurred severally as can be observed from Fig. 1; their duration can be identified from Fig. 2. This cannot be said of low-frequency sampling which relies on a single occurrence of worst-case gas concentration. High temporal resolution time series data gives greater confidence that the 'worst case' concentration has been observed and also tells us more about the temporal dynamics of the system. As confidence increases with increasing representative data, CDC can become a useful tool for risk assessment.

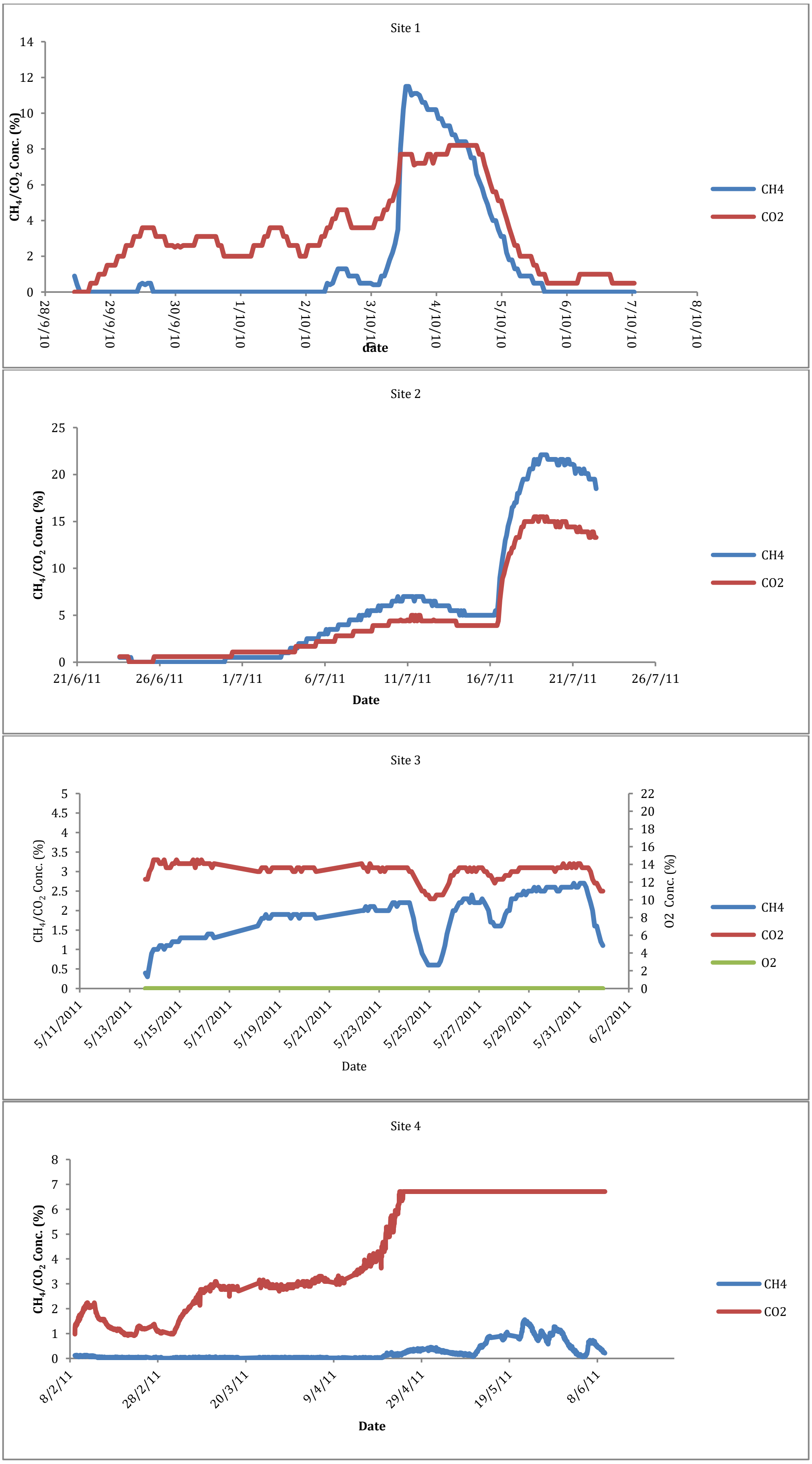

Fig. 1: Graph of CH_4/CO_2 concentration in boreholes at 4 different sites showing the variation of concentration with time

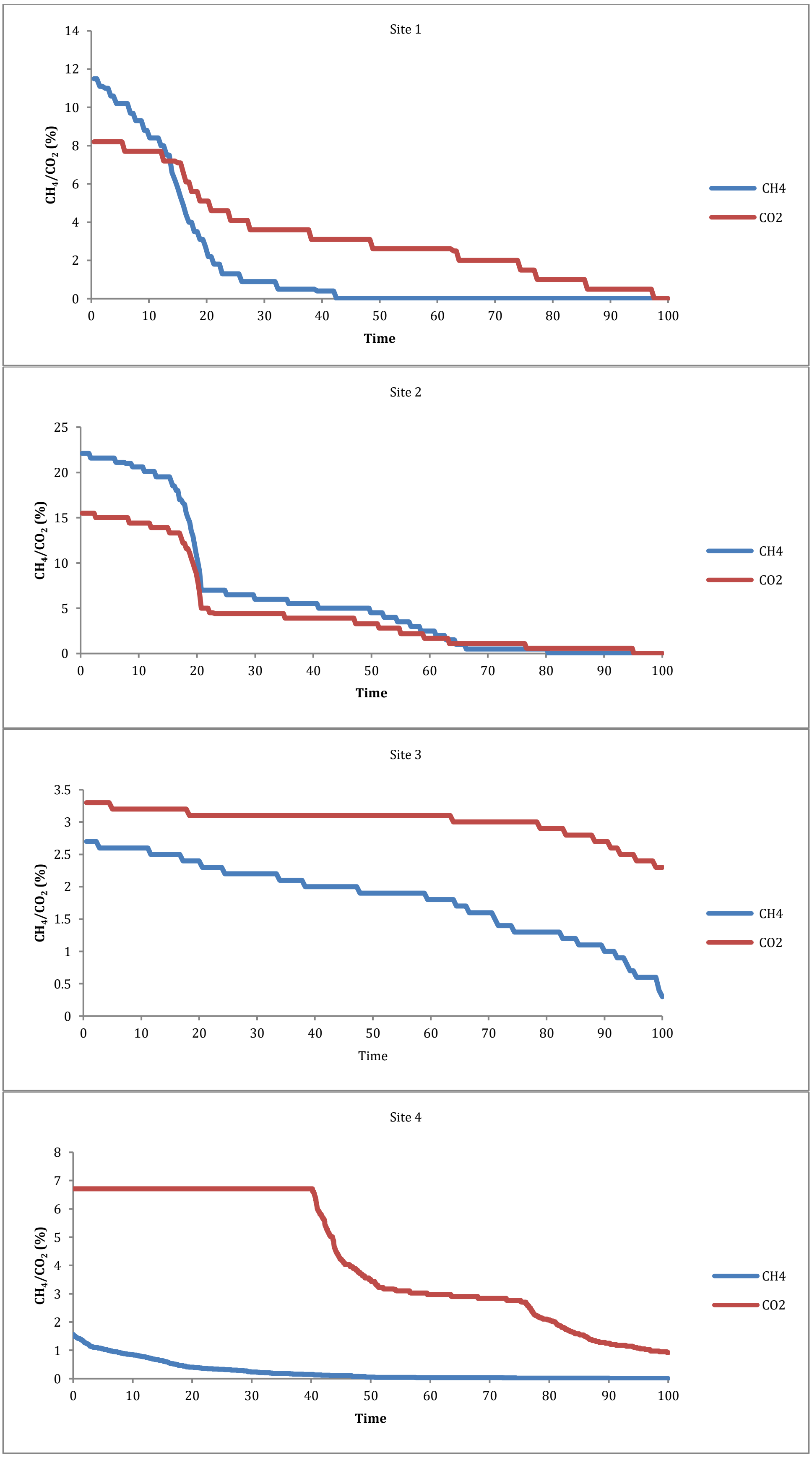

Fig. 2: CH_4/CO_2 concentration duration curve resulting from time-series data from the 4 sites (Fig. 1). The percentage of time that concentration exceeded a 5% and 1% trigger value for CH_4 and CO_2 respectively can easily be observed from the graphs

4. Conclusion

The concept of the Concentration Duration Curve has shown to be a better technique for ground-gas risk assessment. It is an improvement upon the current method which relies on a single occurrence of the worst-case ground-gas concentration (obtained by spot sampling) in that it considers several occurrences of worst-case ground-gas concentration obtained through continuous sampling. This is because concentration can change and can change fast, so confidence in detecting a worst-case by conventional (bi-weekly) sampling is low and therefore inimical in assessing risks of explosion and asphyxiation. There will also be large errors for Greenhouse gas fluxes derived from single measurements. Data analysis with time in percentage helps to determine how long during the monitoring period, CH_4 and CO_2 concentrations exceeded the GSV (trigger values) of 5% and 1% respectively. This technique can be applied to any ground-gas provided the trigger value is known.

5. Recommendation

Given that the worst case may not happen during the monitoring period, there is, therefore, a requirement to predict worst-case ground-gas concentration. Prediction of worst-case concentration of ground gases requires an understanding of the processes (generation and migration) responsible for controlling gas concentration.

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Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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