Comparative analyses of closed-landfill Methane (CH₄) and Carbon dioxide (CO₂) concentrations

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Abstract
The time series data obtained from in-borehole measurement of CH_4 and CO_2 from a landfill site in Manchester, UK are given. Analysis reveals that they were variable for the period under investigation. There is a significant positive correlation between ground CH_4/CO_2 concentrations and their monitoring time. During this period, CH_4 concentration has increased from 0.5% to 62.7%. Similarly, CO_2 concentration has increased from 0.6% to 35.5%. Both gases have positive correlation coefficients of 0.5671 and 0.6653 respectively with time horizon of June – September 2011. Also, the two gases exhibit positive correlation coefficient of 0.9205 with each other; indicating that emission of CH_4 creates potential for emission of CO_2 and vice versa.

Keywords: Greenhouse gas; Global warming potential; Climate mitigation policies; Explosive mixture; Asphyxiation; Risk prediction; Closed landfill; Gasclam; Environmental controls.

1. Introduction
Landfills generate significant amounts of various gases during their active life and for a period of time after their closure [1]. Methane and carbon dioxide are the two major gases mostly generated in landfill emissions [2-6]. Volatile organic compounds (VOCs) are equally generated [7], however; they are usually in trace concentrations [8]. Landfill gas is produced by the decomposition of organic content of waste such as food, garden, wood and paper waste [9]. They are emitted into the atmosphere and can also travel long distances in the porous space of the soil medium. Their migration into the indoor or ambient environment is either by vapour intrusion, vapour emission or vapour release [8].

Globally, methane emissions from landfill accounts for about 30 teragrams per year or 6% of the total global methane emissions [10, 11]. In UK alone, landfill accounted for about 46% of the total methane emissions during 1996 [12]. The global emission of carbon dioxide from the soil respiration ranges from 68×10^{15} gcyear^{-1} [13] to 75×10^{15} gcyear^{-1} [14]; the magnitude of which depends on the activities of the belowground microbial community and root respiration [15]. Moreover, CH_4 and CO_2 are produced from several other sources containing biodegradable organic materials [16]. They can be trapped in materials such as coal and peat, and be released during activities like mining and pilling respectively [16] into the atmosphere.

Methane is regarded as the second most important anthropogenic greenhouse gas in the atmosphere next to carbon dioxide [12, 17]. Its global warming potential for a time horizon of 100 years is 25, which makes it an attractive target for climate mitigation policies [17]. It has a net life time of about 10 years

[17]. Methane is highly explosive at concentrations of approximately 5-15% by volume in air [9] and can accumulate to dangerous levels virtually undetected. It can also act as an asphyxiant and in particular circumstances it may be toxic.

Carbon dioxide on the other hand presents similar hazards to that of methane. It also poses an asphyxiation hazard when it collects in an enclosed space by displacing the existing air and creating an oxygen deficient environment [18]. CO_2 also causes adverse health effects, unconsciousness or even death at relatively low concentrations (at approximately 5% by volume in air) [9].

Methane and carbon dioxide are two main types of greenhouse gases with widely different warming potential. Though the concentration of CH_4 in the atmosphere is lower than CO_2 but it has 22 times the warming potential of CO_2 on a 100-yr time scale, therefore, it may have significant impacts on global climate change [19]. The present CO_2 concentration in the atmosphere is 384.8 ppm while the present CH_4 concentration is 1.74 to 1.86 ppm [20]. The annual increasing rate of the concentration of CO_2 and CH_4 in the atmosphere is 0.5% and 0.8%, respectively [21].

Given the fact that landfill soil is majorly made up of CH_4 and CO_2, there is a requirement to determine whether a change in one of the gases would bring about a concomitant change in the other and also how both correlate with time. This is particularly pertinent, since any variation to and from the soil would help in controlling atmospheric greenhouse effect. This paper uses time series data to establish these relationships.

2. Materials and method

The datasets analysed in this work were obtained with the help of an in-borehole ground-gas monitor, Gasclam (Ion Science, UK). This instrumentation has the capability to monitor continuously and simultaneously various ground-gases ($CH4$, CO_2, CO, O_2, H_2S, and VOCs) and their environmental controls (temperature, barometric pressure, borehole pressure and soil water depth) on hourly sampling basis unmanned for up to three months. It logs long term, real trend information, allowing informed decision to be made on accurate, reliable data – a revolution in gas management and prediction. It measures the gases with the aid of the sensors incorporated into it. Its sampling frequency can be set and is variable from two minutes, to once daily. Data is downloaded to a PC or viewed remotely using the optional GPRS telemetry system.

The instrument was installed in a Landfill site in Manchester, UK. The gas monitors were set sampling on hourly basis and left in-situ to ensure a continuous monitoring of the ground-gases. By doing this, it gives one time series behaviour of the individual gases and their controls allowing room for prediction of their risk. This paper, however, does not look into their risk prediction, but investigates the relationship between two of the gases (that is, CH_4 and CO_2) in landfill soil.

3. Results

The time series data of methane and carbon dioxide concentrations collected for the months of June, July, August and September in 2011 are as shown in Figures 1-4 respectively. These figures illustrate the hourly concentrations of methane and carbon dioxide for the stated months. Figures 5-8 illustrate the relationships between methane and carbon dioxide for the respective months above. Figure 9 is the graph of methane and carbon dioxide against time for the entire monitoring period whilst Figure 10 displays the graph of methane against carbon dioxide concentrations for the same time horizon.

4. Discussions

Figures 1-4 show that methane and carbon dioxide concentrations are all variable. Figure 1 shows initial methane concentration to be 18.5%. It then rose to 25% and remained fairly constant for the next 300 hours and then dropped to 0%. From 0%, it rapidly increased to 60.9% and remained fairly constant for 211 hours before going down to 0% again. Carbon dioxide followed the same trend, however; its concentration is much lower than that of methane.

Figure 2 shows very high variability of methane and carbon dioxide concentrations with initial methane concentration as 51.7%. It then rose to 60% within 11 hours and remained fairly constant for the next 41 hours before going down to 20.3%. It then quickly rose to 60.9% and remained there until after 200 hours and then dropped to 10%. Carbon dioxide had initial and final concentration of 26.7% and 29.1% respectively but peaked at 34.1%. Once again, carbon dioxide shows the same trend with methane.
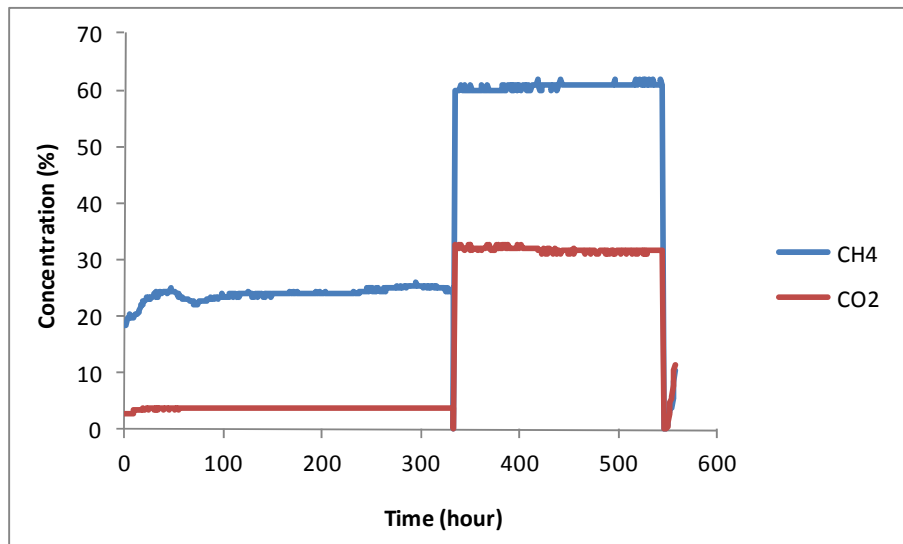
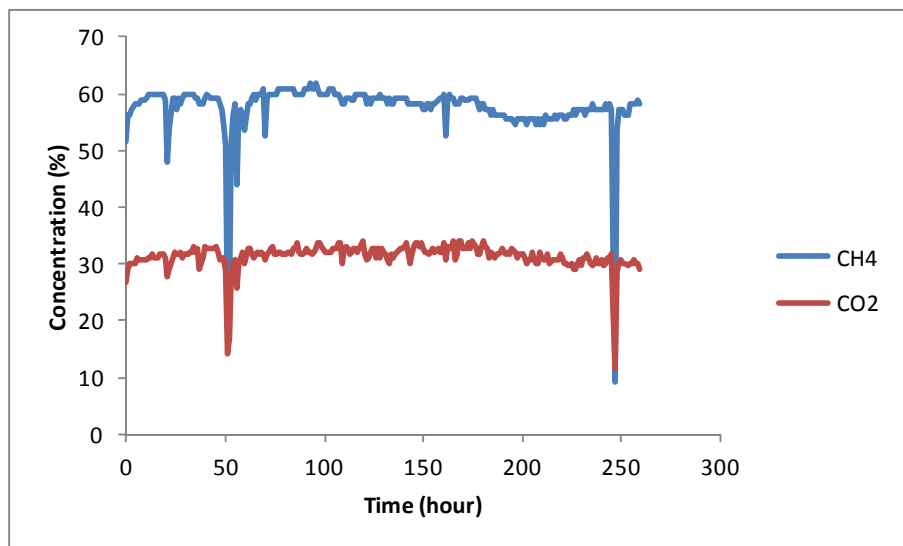Figure 1. Hourly concentrations of methane and carbon dioxide (June, 2011)

Figure 2. Hourly concentration of methane and carbon dioxide (July, 2011)
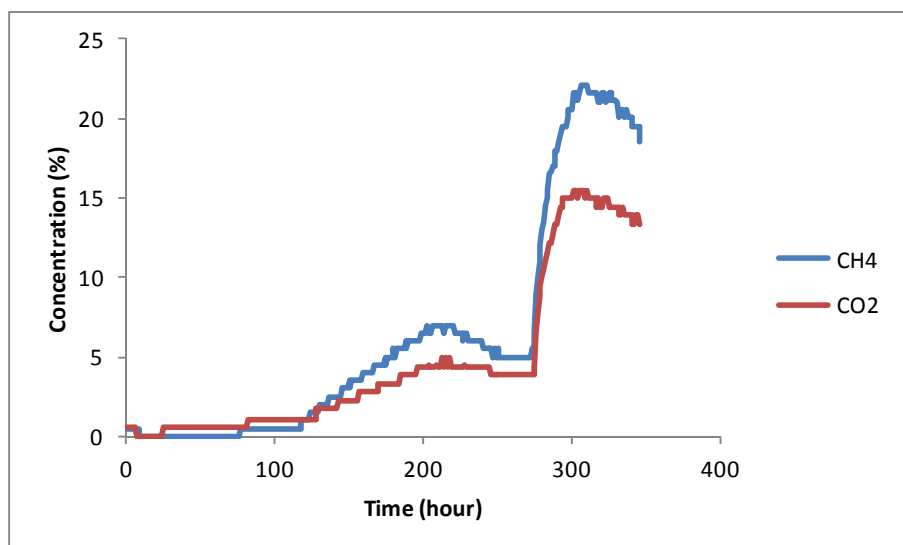

Figure 3. Hourly concentration of methane and carbon dioxide (August, 2011)
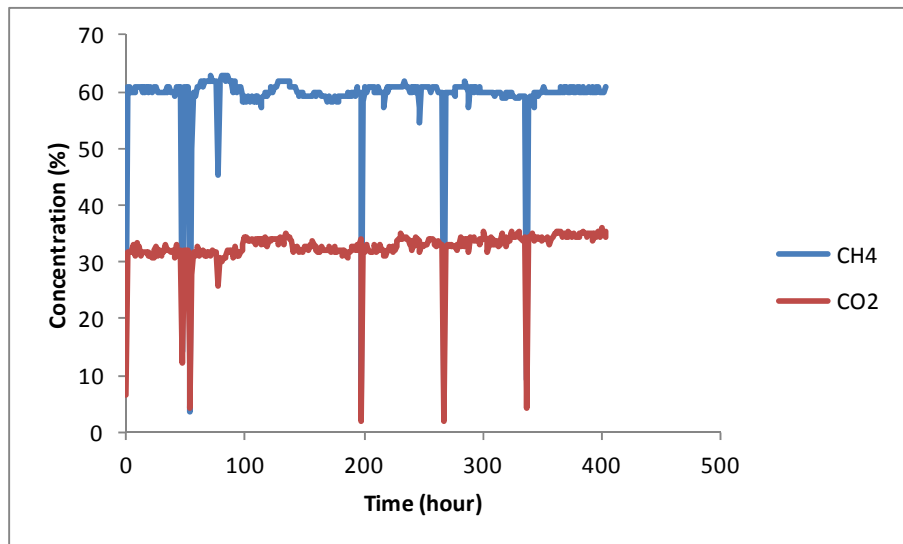
Figure 4. Hourly concentration of methane and carbon dioxide (Sept., 2011)
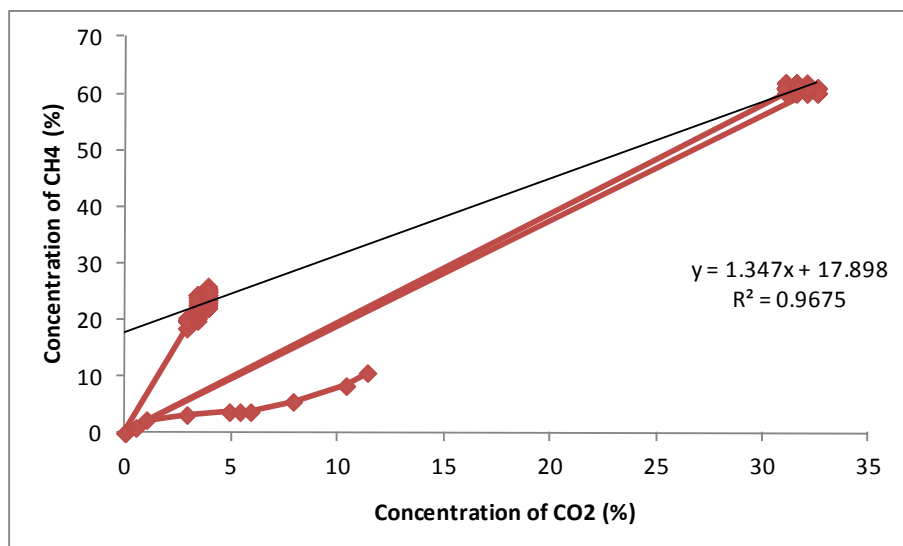

Figure 5. Graph of methane concentration against carbon dioxide concentration (June, 2011)
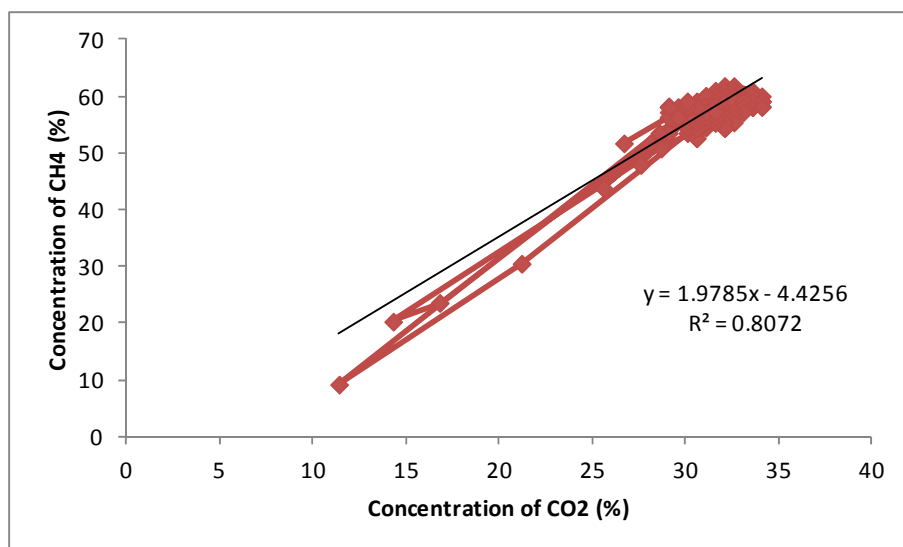

Figure 6. Graph of methane concentration against carbon dioxide concentration (July, 2011)
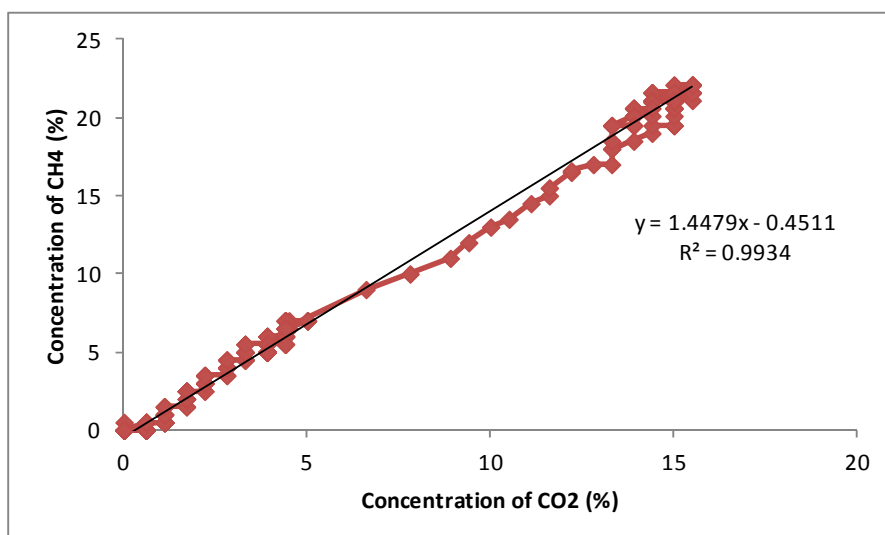
Figure 7. Graph of methane concentration against carbon dioxide concentration (August, 2011)
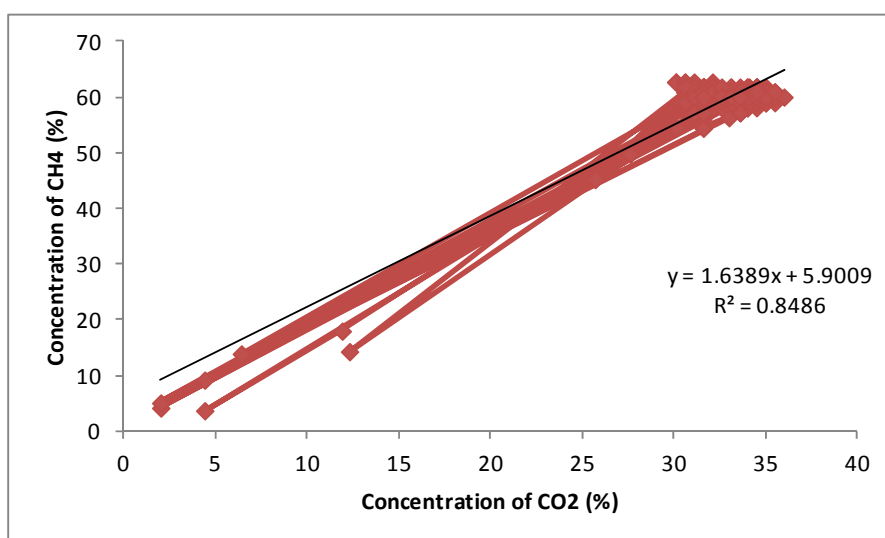

Figure 8. Graph of methane concentration against carbon dioxide concentration (Sept., 2011)
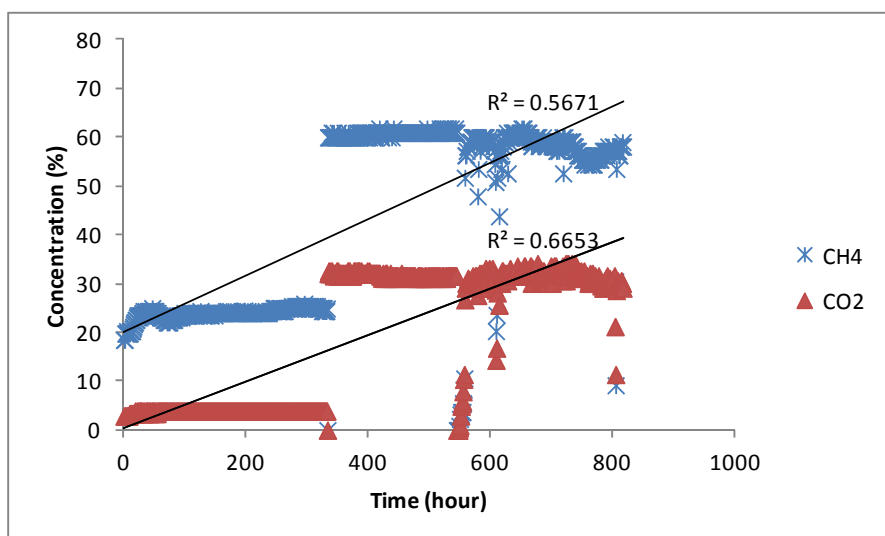

Figure 9. Graph of CH_4 and CO_2 concentrations against time. The correlation is for the entire monitoring period (June-September, 2011)
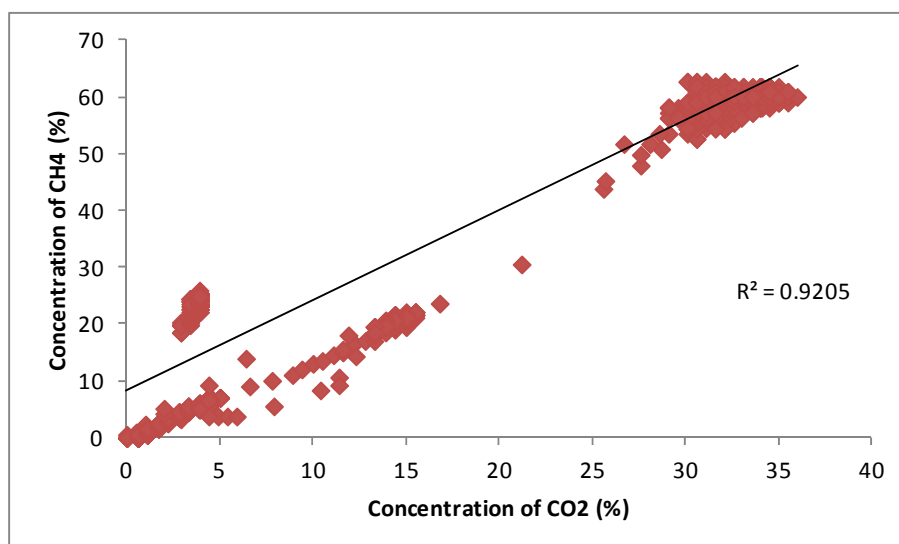
Figure 10. Graph of methane concentration against carbon dioxide concentration for the entire monitoring period (June-September, 2011)

Figure 3 shows the initial methane and carbon dioxide concentrations to be 0.5% and 0.6% respectively. They then remained constant for 6 hours and dropped to 0%. Methane concentration stayed at 0% for 70 hours and then went back to 0.5% and remained there for 41 hours before it gradually peaked at 21.6% and remained fairly there until the data was downloaded. Carbon dioxide on the other hand remained at 0% for 18 hours before going back to 0.6%. It then remained constantly there for 57 hours before gradually going up to 15.5% and fluctuated around this until the end of the monitoring period.

The trend of methane and carbon dioxide concentration in Figure 4 resemble those of Figure 2, however; the frequency of the rising and falling of their concentrations is higher than those of Figure 2. Methane had the lowest and highest concentrations of 13.9% and 62.7% respectively, while carbon dioxide had 6.4% and 35.5% as its lowest and highest concentrations respectively.

Figures 5-8 show graphs of methane against carbon dioxide. They display the correlations of methane with carbon dioxide. Methane had correlations of 0.9675, 0.8072, 0.9934, and 0.8486 with carbon dioxide in Figures 5-8 respectively. Methane and carbon dioxide had correlations of 0.5671 and 0.6653 (Figure 9) respectively with time over the entire monitoring period and also a correlation of 0.9205 (Figure 10) with each other for the same time scale.

5. Conclusions

- The very high concentrations of both the methane and carbon dioxide are significance of increased emission of these gases from landfills into both indoor and ambient atmospheres. This trend could be attributed to their environmental controls.
- The structure of time variation of the gases is a proof that higher concentrations should be expected in the nearest future.
- The high positive correlations between methane and carbon dioxide are indications that the emission of methane incites a concomitant emission of carbon dioxide and vice versa.

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