Methane production, recovery and emission from two Danish landfills

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Landfill gas (LFG), mainly consisting of methane (CH4) and carbon dioxide (CO2), is produced by the anaerobic digestion of biodegradable waste deposited in landfills. CH4 is a greenhouse gas with global warming potential 28 times that of CO2 over a period of 100 years. The produced CH4 in landfills can be recovered and utilized for the production of electricity and/or heat. Higher recovery of CH4 could result in lower CH4 emissions into the atmosphere, and thus lower the contribution of landfills to climate change. Moreover, higher CH4 recovery can result in higher production of heat and electricity, leading to higher revenue for landfill owners. Therefore, it is important to understand the factors that can affect CH4 recovery from landfills. The amount of CH4 recovered from a landfill is indeed a function of the amount of CH4 produced in a landfill. The amount of produced CH4 in a landfill is governed by the waste composition and can be affected by many factors, including temperature, moisture, and chemical or microbial reactions, which occur simultaneously inside a landfill, such as corrosion. Moreover, the amount of CH4 recovered from a landfill depends on the efficiency of the gas recovery system, which is affected by its design and management, as well as the presence and type of top cover at the landfill. Furthermore, CH4 recovery from a landfill can be affected by changes in meteorological parameters. For instance, changes in barometric pressure affect the pressure gradient, which is the driving force for advective gas transport, between inside the landfill and the atmosphere, and thus potentially can impact CH4 recovery. The overall goal of this PhD project was to address specific challenges regarding CH4 production and recovery at landfills. The PhD project focused on three topics: 1) an in-depth investigation of CH4 production from shredder waste (SW) at landfills, 2) the determination of gas recovery efficiency at two adjacent Danish landfills by field measurement, and 3) the influence of meteorological parameters on gas recovery from landfills. This PhD project focused on two adjacent Danish landfills, Stige Ø and Odense Nord, which are connected to the same gas recovery system. In order to assess the CH4 production from SW at landfills, SW was sampled from the Odense Nord landfill, size-reduced and characterized in terms of total solids (TS), volatile solids (VS), total carbon (TC), total organic carbon (TOC) and biogenic carbon (BioC). SW samples were incubated to measure their first-order decay kinetic constant (k-value), under different operating conditions (temperature and moisture), and their biochemical methane potential (BMP). In addition, four main metals present in SW (Fe, Al, Zn and Cu) were examined for their ability to produce available H2 for methanogens. The characterization results showed that a high fraction of the organic carbon (47-61%) in SW is fossil carbon. Moreover, high TS content (62-91%) in the waste samples showed that the samples were fairly dry. The measured BMPs were 1.5-6.2 kg CH4/ton waste, while the measured k-values were 0.033-0.075/yr at room temperature, 0.220-0.429/yr at 37 ºC and 0.235-0.488/yr at 55 ºC. The fine fraction of SW obtained after sieving showed a lower BMP and k-value in comparison to the unsieved SW, meaning that landfilling of the fine fraction of SW could result in lower CH4 production in comparison to unsieved SW. Carrying out the incubation experiments under different operating conditions indicated the high dependency of the CH4 production rate on temperature and moisture. H2 was produced by biocorrosion of Fe, Al and Zn and utilized by methanogens to convert CO2 into CH4. The addition of Al and Zn to the incubated SW resulted in higher CH4 production. Relatively high CH4 production from SW at landfills and the unusual gas composition (high CH4 and low CO2 content) are most likely due to methanogens converting the existing CO2 in the produced LFG into CH4, using the H2 produced by biocorrosion of Al and Zn. In order to determine the gas recovery efficiency at the landfills, a set of field activities was performed: whole-site CH4 emissions were measured by the tracer gas dispersion method (six measurement campaigns), while CH4 oxidation in the top layer of the landfills was measured by stable carbon isotopic analysis (two measurement campaigns). The CH4 recovery rate, which was provided by landfill operators, was the sum of the CH4 recovered from both landfills. In addition, the total CH4 production rate was estimated using the Afvalzorg model and compared with the results of field measurements. Total CH4 emissions from the two landfills combined were 29-50 kg/h, while the measured CH4 oxidation efficiency was 6-37%. The CH4 recovery rate from both landfills combined was 85-115 kg/h. The calculated gas recovery efficiency was 59-76%, which indicated a high potential for improvement in the gas recovery system at landfills. The average total CH4 production rate determined by field measurements (sum of methane recovered, emitted and oxidized) was 147 kg/h, which was close to the estimated total CH4 production rate of 154 kg/h by the Afvalzorg model. The calculated gas recovery efficiency, along with the observed major CH4 emission areas during the surface screenings, can be used for developing a plan for improvement of the gas recovery system. In order to investigate the influence of meteorological parameters on LFG recovery, correlation coefficients and p-values were calculated between the gas recovery rate and meteorological parameters. Barometric pressure, wind speed, ambient temperature and solar radiation were the chosen meteorological parameters. Four periods (from a few days to approximately one month) in 2015 and 2016 were studied. These four periods were chosen because the gas recovery system was not manually adjusted in these periods by the landfill operators. Relatively high correlation coefficients were observed between LFG data (LFG CH4 concentration, LFG flow and CH4 flow) and barometric pressure ($|r|$ = 0.37-0.73), while higher correlation coefficients were observed between LFG data and changes in barometric pressure ($|r|$ = 0.80-0.93). Moreover, a strong correlation was observed between wind speed and LFG data in winter ($|r|$ = 0.75-0.77), but not in summer ($|r|$ = 0.05-0.30). The correlations of LFG data with barometric pressure, changes in barometric pressure and wind speed were statistically significant (p < 0.01) and observed visually in scatterplots. The slope of the linear regression between changes in barometric pressure and LFG data can be used to predict changes in recovered LFG as a function of changes in pressure. As LFG recovery data only correlated weakly with ambient temperature ($|r|$ = 0.12-0.49) and solar radiation ($|r|$ = 0.03-0.21), these two parameters were not found to affect LFG recovery.

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