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Review

Performance of the biotic systems for reducing methane emissions from landfill sites: A review

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ABSTRACT

Today, solid waste landfilling is considered to be one of the major environmental concerns due to its significant methane (CH_4) production. Although selecting landfill as a viable option for solid waste management should be given the last priority due to considerable greenhouse gas (GHG) emissions in comparison to other waste management technologies. However, it is still a popular way of monitoring solid waste production throughout the world. It is generally estimated that landfill gas (LFG) accounts for more than half of the GHG emissions from waste sectors, so it is globally regarded as a major environmental challenge. Therefore, it is vital to promote management techniques to reduce CH_4 emission from landfills to address the global warming nuisance and decrease the human risks concerning LFG migration from landfill sites. Biotic oxidation of CH_4 in landfill cover soil has been given utmost attention for mitigation of CH_4 emissions over the recent years. CH_4 oxidation is a process which naturally takes place through different layers of cover soil due to the profusion of methanotrophic organisms. The contribution of these bacteria to CH_4 oxidation is affected by several environmental controlling factors. These factors include the nutrient requirement, and the operating conditions such as pH, temperature, and moisture content of the cover soil, which are considered to be the main bioreactor bed. The prolonged operation of the biotic systems was found to be adversely influenced by the self-degradability of the material, which resulted in more CH_4 production rather than oxidation. Such conditions might result in the formation of pore-clogging exopolymeric substances (EPS) that restricts O_2 penetration to the cover soil and CH_4 oxidation potential. These issues resulted in the poor performance of the biotic systems and no potential solution has not been clearly presented in the literature. Therefore, the aim of this study was to review the recent field and laboratory studies associated with different types of soil and biotic systems. In addition, the advantages and disadvantages of every biotic process to reduce CH_4 emission from landfill sites were also discussed.

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1. Introduction

Municipal solid waste (MSW) has become an increasing environmental concern due to the rapid industrialization and population explosion throughout the world. Newer methods of MSW handling such as contemporary unified waste management have been employed instead of the conventional open dump technology, which was common in the 1960s (Abichou et al., 2009). The approach of the current waste management systems is to reduce the volume of the solid waste produced at the origin via the incorporation of three aspects: the reuse and recycling of refuse, energy recovery from refuse and residual waste management (Kollikkathara et al., 2009). Several alternative options have been implemented to manage accumulated solid waste to reduce the necessity of landfilling. However, recent investigations in the US show that over 50% of the MSW produced is currently decomposed through landfill sites. This clarifies that landfilling is the most common approach to solid waste management (USEPA, 2012; Weitz et al., 2002).

The most significant environmental nuisance of the landfill approach is the landfill gas (LFG) production resulting in thousands of tons of the greenhouse gas (GHG) to be vented into the global atmosphere. The LFG is mainly composed of CH_4 (50–55%) and CO_2 (40–45%), which are generated during the anaerobic digestion of the solid waste through landfill sites (Ayalon et al., 2001; Scheutz et al., 2009a). Over the recent years, researchers have followed two approaches to determine the typical gas generation rate. The first group has used comprehensive field-monitoring programs at US landfill sites. However, the second group has modelled the field-gas production rates in laboratory investigations (Du Plessis et al., 2003; Chanton et al., 2011a, 2011b; Spokas et al., 2011; Haubrichs and Widmann, 2006; Abichou et al., 2011). The persistence period (the gas remains in the atmosphere) of CH_4 is conventionally 12 years and in comparison to CO_2 (with the persistence period of 172 years); it is regarded as a fleeting GHG. Nonetheless, the radiative capacity of CH_4 ($3.79 \times 10^{-4}\,W\,m^{-2}\,ppb^{-1}$) is much higher than CO_2 ($1.4 \times 10^{-5}\,W\,m^{-2}\,ppb^{-1}$) (IPCC, 2007). As a result, CH_4 has been found to be the most vigorous GHG with a worldwide climate warming potential of 25 times throughout a time period of 100 years (Kammann et al., 2012). Between 65% to 80% of CO_2 released into the air is dissolveed into the ocean over a period of 20–200 years. The rest is removed by slower processes that take up to several hundreds of thousands of years, including chemical weathering and rock formation (USEPA, 2012). This means that once in the atmosphere, CO_2 can continue to affect climate for thousands of years. CH_4, by contrast, is mostly removed from the atmosphere by chemical reaction. Thus although CH_4 is a potent GHG, its effect is relatively short-lived.

Landfill sites are also likely to generate other non-methane volatile organic compounds (VOCs) including hydro-chlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs) which are typically generated at low scales (Bogner et al., 2010). Based on the recent results published by EPA on the US record of GHG emissions in 2010, landfills are the third main source of anthropogenic CH_4 emission. This is roughly 16.2% of the anthropogenic CH_4 emissions throughout the US (USEPA, 2012).

Therefore, over the recent decades, the mitigation of LFGs from landfill sites via efficacious gas management systems has received utmost attention. Typical current approaches include the application of an LFG collection system and a landfill cover technology or an integration of both. Modern high-tech landfills are equipped with gas collection systems containing vertical wells and horizontal collection systems. They consist of cylindrical pipes with precisely arranged perforations enclosed by a material with high hydraulic conductivity (Barlaz et al., 2009). The aforementioned collection systems are located within the waste layers to trap and flare CH_4 in the subsequent steps or recover it as a main source of energy. To trap LFG via gas collection system, a negative pressure should be applied to the pipe's collection point to augment poten LFG collection and recovery in landfill sites (IPCC, 2007; Park and Shin, 2001). Gas collection systems are more useful during the active phase of landfill sites as they generate a large amount of CH_4 gas due to anaerobic waste decomposition. This leads to the gas flaring which reduces the associated cost.

According to the US Clean Air Act New Source Performance Standards (NSPS), gas collection systems are recommended for installation in landfill sites. This should be within the first few years after the ultimate cover was installed on the waste cells or within the 5 years after the final time that fresh waste was disposed of in the landfill waste cells (IPCC, 2007). The critical point in effectively managing the generated LFG in landfill sites is to estimate the LFG composition and its impermanent alterations. Thus, several LFG generation models have been widely developed to address this issue (IPCC, 2007). Zero, first, and second order decay equations are commonly used to estimate the level of LFG produced (Scheutz et al., 2011b). Kamalan et al. (2011) have discussed various LFG generation models in a comprehensive review. The first order models represent the physio-chemical features of the solid waste as well as the site specific conditions. The data achieved from landfills also indicate the quantity of the refuse under consideration. Therefore, the first order decay model is the most applicable approach to determine the LFG generation rates (Kamalan et al., 2011). Several first order models such as Mexico, IPCC, SWANA, GasSim, Afvalzorg, LandGem, EPER France, and TNO have been widely used by researchers, while LandGem is considered to be the most commonly applied gas generation model and it is particularly used in the US for MSW landfills (Kamalan et al., 2011).

There are several studies in the literature on the efficacy of LFG collection systems (Spokas et al., 2011; Barlaz et al., 2009). According to these studies, the efficacy of a gas collection system is associated with the cover system (intermediate, daily, or final) and rate of efficacy varies from 50% to 95%. The LFG flaring is mainly designed as a complementary process typically coupled with gas collection systems and it generates CO_2, which is a less harmful GHG in comparison to CH_4. However, CH_4 flaring can release some volatile organic compounds (VOCs) as by-products into the atmosphere, which have been found to adversely affect human health (Hettiarachchi et al., 2009). In addition, the application of gas collection systems in old or small landfill sites with low LFG generation