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The in situ aeration in an old landfill in China: Multi-wells optimization method and application

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ABSTRACT

The optimization design of well spacing (WS) and aeration rate (AR) is crucial to the in situ aeration system operation in under long-term and high-efficiency conditions. This optimization design aims to transport additional air into landfills and to develop an improved oxygen environment for enhancing aerobic degradation. Given the specific pore structure distribution within landfills, providing sufficient oxygen in all waste bodies in field sites through gas wells is difficult. The design of well distribution also lacks adequate criteria. In this work, the multi-well optimization aeration method (MWOAM) was proposed to select the WS and AR from prediction results that consider gas transport properties by maximizing oxygen storage ratio (OSR) as the key objective threshold. This method was applied to the aeration restoration engineering in Jinkou landfill, which represents the first full-scale application of an aeration project in China, to optimize the operation scheme of the aeration system. Results of the gas concentration monitoring show that the trend of the OSR with aeration time based on the measurement agrees with the prediction. The oxygen and methane contents remain high and low within the landfill during the aeration process, respectively. Moreover, the temperature in the waste body did not exceed the upper limit value. These results suggested that the MWOAM is an effective means of supplying sufficient oxygen content across the landfill body and extend the aeration system operation for the long term. Therefore, this work provides reliable evidence to support the design and operation management of the aeration systems in full-scale landfills.

1. Introduction

Aeration technology is the major method for enhancing in situ remediation of landfills around the world (Ritzkowski and Stegmann, 2012; Townsend et al., 2015). An aerobic environment in landfills results from the air-blower and gas wells. Aeration rate (AR) and well distribution are the key design factors for the operation of aeration systems (Cossu and Cestaro, 2005; Liu et al., 2016a; Raga and Cossu, 2013; Xu et al., 2016).

The AR in full-scale landfills is determined through lab-scale tests because long-term aeration tests in landfills are insufficient (Ritzkowski and Stegmann, 2007). Moreover, the waste samples used in lab-scale aeration tests are difficult to use because of the upscaling effect. In major lab tests, the high AR values ranging from5.7 L/kg to 374 L/kg DM per day are generally set to decrease the aeration time (Giannis et al., 2008; Nikolaou et al., 2010; Gamperling et al., 2011; El-Fadel et al., 2013; Hrad et al., 2013; Slezak et al., 2015). Given the anisotropy of pore systems and high water levels in full-scale landfills, the ARs used are smaller in landfills than in lab tests. For example, Ritzkowski et al. (2006) applied the ARs ranging from 0.2 L/kg to 0.6 L/kg DM per day in a lab test. By contrast, the AR used in landfills is0.3 L/kg DM per day. This conservative AR could lead to sustained long-term operation of the injection system (Table 1).

However, a relatively high AR results in the rapid rise of temperature, especially in areas with high water and organic matter contents (Ko et al., 2013; Hrad et al., 2013). In many aeration projects, the interim shutdown operation of injection blowers is conducted to reduce the temperature of the waste body

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Table 1
Comparison of aeration operation in different landfills.

Site	Area (ha)	Storage capacity	Aeration rate	Aeration plan	Aeration period/landfilled time	Aeration method
U.S. Columbia County landfill[a]	1.6	45200 m^3	74 $L/h/m^3$ 1.7 L/kg DM/day[*]	Continuation	1.5 years/1.5 years	Injection
U.S. Atlanta Landfill[a]	1.0	49000 m^3	122 $L/h/m^3$ 2.9 L/kg DM/day[*]	Continuation	0.75 years/3 years	Injection
German Kuhstedt Landfill[b]	3.2	220,000 m^3 132,000 tons DM	0.29 L/kg DM/day	Continuation	6.25 years/13–35 years	Injection and extraction Low pressure
German Dorfweiher landfill[c]	1	–	Max 1350 m^3/h Changed	Interim shutdown	1.08 year/7–14 years	Injection High and low pressure
Austrian Vienna landfill[d,e]	2.6	200,000 tons WM	First stage: 0.06 L/kg DM/day Second stage: 0.09 L/kg DM/day	Continuation	3.1 years/21–31 years	Injection and extraction Low pressure
U.S. New River Regional landfill[f]	4	–	1400–2100 m^3/Mg waste Changed	Interim shutdown	–/5–11 years	Injection and extraction Low pressure
Italy Landfill C[g]	1	60,000 tons DM	0.29 L/kg DM/day	–	1 year/1970–1983	Injection and extraction Low pressure
Italy Modena Landfill[h]	5	630,000 tons	610 m^3/h 0.02 L/kg DM/day[*] Changed	Interim shutdown	1.1 years/1985–1988	Injection and extraction Low pressure
China Jinkou Landfill[i]	14.93	2239500 m^3	0.08 L/kg DM/day	Continuation	2 yr/8–16 yr	Injection and extraction Low pressure

[a] Hudgins and Harper (1999).
[b] Ritzkowski et al. (2006).
[c] Oncu et al. (2012).
[d] Hrad et al. (2013).
[e] Hrad and Huberhumer (2016).
[f] Ko et al. (2013).
[g] Raga and Cossu (2014).
[h] Raga et al. (2015).
[i] This project.
[*] Artificial conversion.

and avoid safety risks (Oncu et al., 2012; Ko et al., 2013; Raga et al., 2015) (Table 1). This action is mainly due to the excessive accumulation of the injected air close to the well portal, in which the temperature sharply increases with the chemical reaction rate. Therefore, an effective air injection and extraction rate is important to avoid high temperatures in certain parts of aerobic landfills.

The effective oxygen emission through the whole landfill body is achieved by improving the coordination between the injection/extraction rate and well spacing (WS). Certain researchers have proposed assessment theories and methods for oxygen transport in landfills, although no standard is used for the design of the aeration systems around the world. This achievement will aid in developing an excellent aeration scheme.

In the modeling aspect, Cossu and Cestaro (2005) developed a 2D mathematical flow model to predict the radius of influence of a generic well with the injection or extraction operation in landfills. Yuan et al. (2009) developed a 1D advection–diffusion model to simulate the methane transport and oxidation within a lab compost biofilter. Fytanidis (2014) developed a CFD coupling model on the basis of fluid dynamic theory to describe methane oxidation in landfills considering the aerobic biodegradation of the organic fraction of the municipal solid waste.

In the field test aspect, Hrad et al. (2013) suggested that spatial aeration efficiency cannot be improved by increasing the AR in high water levels within landfills. Raga and Cossu (2014) calculated the WS based on waste quality and mechanical conditions from the results of the in situ aeration tests. The preferential path shows a significant effect on the oxygen flow and distribution in landfills (Ritzkowski and Stegmann, 2013; Yazdani et al., 2015; Liu, 2017). Moreover, the measurement of gas flow in field sites suggests that the capacity of the methane oxidation reaction, pore structure, heat release from aerobic reaction, and the final cover of waste body provides a significant effect on the gas transport in landfills; this measurement also contributes to the gas well design (Lee et al., 2002; Yu, 2009; Jung et al., 2011; Liu et al., 2014; Liu et al., 2016b). These practical examples adequately indicate that the appropriate oxygen content during aeration system operation should be improved by optimizing the AR and WS in landfills.

In summary, WS and AR must be modified to maintain the continuity of the aeration system operation and the rationality of the oxygen content within the whole landfill and to fit the practical field site conditions. In the current work, we propose a multi-well optimization aeration method (MWOAM) that could consider the typical conditions in a field site to predict and select the reasonable WS and AR, improve the degradation efficiency in the course of aeration, and ensure continued aeration in the long term and with an ample amount of oxygen. This method was applied to the first and largest remediation project in Jinkou landfill in China.

2. Optimization method

2.1. Optimization program

The optimization program is illustrated in Fig. 1. The main points were as follows. First, the oxygen movement states in a target landfill should be provided by using the gas transport model based on the project conditions. Second, the objective function of the oxygen storage ratio (OSR) should be calculated, and the WS and AR should be selected by using optimization theory and neural networks. Third, the analysis and selection were considered completed when the export OSR had satisfied the reliability

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