Waste Management 63 (2017) 397–409

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Performance and completion assessment of an in-situ aerated municipal solid waste landfill – Final scientific documentation of an Austrian case study

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ARTICLE INFO

Article history:
Received 4 April 2016
Revised 29 June 2016
Accepted 29 July 2016
Available online 23 August 2016

Keywords:
In-situ aeration
Low pressure aeration
Aeration completion
Waste stabilization

ABSTRACT

By converting anaerobic landfills into a biologically stabilized state through accelerating aerobic organic matter degradation, the effort and duration necessary for post-closure procedures can be shortened. In Austria, the first full-scale application of in-situ landfill aeration by means of low pressure air injection with simultaneous off-gas collection and treatment was implemented on an old MSW-landfill and operated between 2007 and 2013. Besides complementary laboratory investigations, which included waste sampling from the landfill site prior to aeration start, a comprehensive field monitoring program was conducted to assess the influence of the aeration measure on the emission behavior of the landfilled waste during the aeration period as well as after aeration completion. Although the initial waste material was described as rather stable, the lab-scale aeration tests indicated a significant improvement of the leachate quality and even the biological solid waste stability. However, the aeration success was less pronounced for the application at the landfill site, mainly due to technical limitations in the full-scale operation. In this paper main performance data of the field investigation are compared to four other scientifically documented case studies along with stability indicators for solid waste and leachate characteristics in order to evaluate the success of aeration as well as the progress of a landfill towards completion and end of post-closure care. A number of quantitative benchmarks and relevant context information for the performance assessment of the five hitherto conducted international aeration projects are proposed aiming to support the systematization and harmonization of available results from diverse field studies and full-scale applications in future.

1. Introduction

In recent years, the interest in controlled and sustainable bio-stabilization of older Municipal Solid Waste (MSW) landfills has increased due to long lasting gas and leachate emissions and costly continuous aftercare (post-closure). In-situ aeration, as a measure to accelerate organic matter degradation by mainly oxidative respiration, seems to be a preferable option to shorten aftercare periods, in particular, for old landfills where gas recovery is no longer economically and technically suitable (Heyer et al., 2005; Rich et al., 2008; Ritzkowski et al., 2006). Landfill aeration might be also used as a preparation measure before landfill mining (Raga and Cossu, 2014; Raga et al., 2015), landfill remediation for old landfills or landfill cells without prior gas collection and treatment (Brandstätter et al., 2013; Hrad et al., 2013; Ritzkowski et al., 2003, 2006) or coupled with leachate recirculation for the purpose of enhanced waste stabilization and leachate treatment (El Fadel et al., 2013; Giannis et al., 2008; Laux, 2015; Öncü et al., 2012; Tran et al., 2014). Moreover, the Intergovernmental Panel on Climate Change (IPCC) has identified landfill aeration as a viable strategy for greenhouse gas (GHG) reductions in the waste sector (IPCC, 2014), and the United Nations Framework Convention on Climate Change (UNFCCC) has already approved this technology for generation of Certified Emission Reductions (CERs) of Clean Development Mechanism (CDM) projects (Ritzkowski and Stegmann, 2010; UNFCCC, 2009).

In general, in-situ aeration is an intervention over a short and controllable time period intended to mitigate both current and potential (long-term) emissions of the landfilled waste. The primary goals of aerobic landfill systems are to increase carbon turnover rates and mineralization processes, achieve a bio-stabilized state, improve leachate quality as well as reduce landfill gas (LFG) formation potential, accelerate waste mass settlements and mitigate current methane (CH_4) emissions (Heyer et al., 2005; Prantl et al., 2006; Ritzkowski et al., 2006).

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http://dx.doi.org/10.1016/j.wasman.2016.07.043
0956-053X/

From a technical point of view there are various aeration technologies and operation concepts, which have been recently reviewed by Ritzkowski and Stegmann (2012). According to this treatise, concepts range from high and low pressure aeration to semi aerobic applications, involving either continuous or intermittent air supply. Low pressure aeration can be further divided into active aeration with off-gas extraction, passive aeration (air venting) and energy self-sufficient long-term aeration. During the last decade, the number of scientific studies investigating the aeration effects on the solid, liquid and gaseous phase both in the laboratory and field increased (Bilgili et al., 2006; Brandstätter et al., 2015; Hrad et al., 2013; Laux, 2015; Öncü et al., 2012; Prantl et al., 2006, 2007; Ritzkowski et al., 2006, 2007, 2016; Sekman et al., 2011). Although several full-scale aeration projects have already been implemented in Europe (Brandstätter et al., 2013; Heyer et al., 2005; Hrad et al., 2013; Laux, 2015; Ritzkowski and Stegmann, 2007; Ritzkowski et al., 2016), North America and Canada (Beatty et al., 2009; Read et al., 2001) as well as Asia (Kim et al., 2010; Liu et al., 2015; Matsuto et al., 2015), there is still a lack of generally accepted criteria for the assessment of waste stabilization success (particularly in terms of long-term emission reduction). Ritzkowski and Stegmann (2013) have already proposed 6 criteria and target values, mainly based on carbon balance approaches including solid waste characterization in combination with emission monitoring data (gas and leachate) to determine the completion (end-point) of an aeration project. However, quantitative data from documented full-scale case studies with respect to long-term trends of gaseous and liquid emissions after the cessation of aeration measures are limited. To the authors' knowledge there is only one comprehensive (Canadian) case study (Beatty et al., 2009) confirming sustained improvements (reductions of methane emissions) for 30 years after aeration completion. Further quantitative data from full-scale studies showing the stabilization effect on landfilled waste following aeration completion are needed to verify proposed stabilization criteria for a broader discussion among experts. These data are also required to contribute useful information for the on-going discussion about when to stop aftercare of currently closed landfills (Scharff, 2011).

In Austria, the first full-scale application of in-situ aeration by means of low pressure air injection with simultaneous off-gas collection and treatment (biofilter) was implemented on an old MSW landfill in autumn 2007, intended to run for about 6 years. Preliminary results on the emission behavior of the waste material after 3 years of operations have already been published in Hrad et al. (2013). In particular, information on the transferability of the results from lab- to full-scale was provided.

The purpose of this paper is to provide new, original results gained during the last three years of operation, and to outline and discuss the waste stabilization success following the 6-years aeration period as well as the lasting effect on gaseous and liquid emissions of the landfilled material after the first year of aeration completion. Performance data of the Austrian case study are also compared to four other scientifically documented aeration projects in terms of waste and leachate quality, carbon discharges as well as landfill temperature and settlement. Stability indicators referenced in the literature for solid waste and leachate characteristics are used to evaluate the data from the diverse landfill aeration studies. A major constraint in comparing different aeration projects is the lack of consistent benchmarks. In this context, the paper intends to act as a stepping stone towards a new approach for the performance and efficiency assessment of aeration projects, which includes a number of quantitative benchmarks and relevant context information of the investigated sites. The performance data can be also used to profile new aeration measures by allowing comparison between various aeration projects and best practice examples.

2. Material and methods

2.1. Landfill site and aeration concept

The total landfill site had an area of 2.6 ha, where 200,000 Mg of untreated municipal and commercial waste were deposited in two different sections (VA01 and VA02) between 1976 and 1995. The first part of the old landfill (VA01) was closed in 1985; the second landfill section (VA02) started operation in 1986 and was closed in 1995. In contrast to VA02, VA01 was installed on a natural clay liner without an artificial impermeable bottom seal and leachate collection system. The depth of disposed solid waste varied between 3 and 18 m. The in-situ aeration plant was installed in autumn 2007 and consisted of 37 gas wells for aeration and collection of exhausts as well as a biofilter for off-gas purification. The air injection and extraction system consisted of 6 distribution networks, which were connected to the operating unit by 3 main aeration and extraction pipes. The aeration plant was operated from the end of January 2008 till the end of 2013 with a total of 31.550 operation hours (69% degree of efficiency) (data status April 2013). Within this time period about 24.6 Mio m^3 air was blown into the landfill body equalling about 780 m^3/h input (or 0.09 L air/kg dry matter d). In March 2011 the landfill operator switched the aeration wells into extraction wells and vice versa in order to enhance oxygen supply, and thus bio-degradation in regions around the former off-gas extraction wells. Solid waste samples were taken prior to aeration start (42 samples), after 2.5 years (41 samples) as well as after 5.5 years of aeration (36 samples) in order to characterize the initial, intermediate and final waste reactivity and other properties. Leachate samples from already existing leachate wells were taken every second month and a set of chemical parameters were analyzed. 28 monitoring probes (for gas quality, temperature, water level, pressure difference to atmosphere) were installed at different depths (1–5 m) between air injection and gas extraction wells enabling the evaluation of the aeration effect in the deposited waste mass of the landfill. Inside the wells the concentrations of CH_4, carbon dioxide (CO_2) and oxygen (O_2) as well as the temperature, water level and pressure difference were periodically monitored (every second month). Even after aeration stop (at the end of 2013) the monitoring of leachate and gas quality was continued for one year. A detailed description of the aeration and monitoring concept is already given in Hrad et al. (2013).

2.2. Complementary laboratory investigations

Complementary laboratory investigations were conducted with waste samples taken from the landfill site in order to determine the potential emission reduction of the landfilled waste and its long-term emission behavior after aeration completion. As described in detail by Hrad et al. (2013) waste samples taken from the landfill site were placed into six 90 L Landfill Simulation Reactors (LSR), which were operated both under aerobic (approx. 1.0 L air/kg dry matter d) and anaerobic conditions for 740 days. In order to investigate the long-term emission behavior of the aerobically "stabilized" waste material, aeration of one LSR stopped after the first monitoring phase (740 days) and emission data was monitored for further 522 days. More comprehensive description on experimental set-up and monitoring is provided in Hrad et al. (2013).

2.3. Chemical and biological analyses

Solid waste samples from the field-scale and lab-scale investigations were characterized for (1) chemical parameters, including e.g. ammonium-nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N), chemical oxygen demand (COD), biochemical oxygen demand