Waste Management 35 (2015) 159–169

Contents lists available at ScienceDirect

Waste Management

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

Performance evaluation of a hybrid-passive landfill leachate treatment system using multivariate statistical techniques

Jack Wallace [a], Pascale Champagne [a,*], Anne-Charlotte Monnier [b]

[a] Department of Civil Engineering, Queen's University, Ellis Hall, 58 University Avenue, Kingston, Ontario K7L 3N6, Canada
[b] National Institute for Applied Sciences – Lyon, 20 Avenue Albert Einstein, 69621 Villeurbanne Cedex, France

ARTICLE INFO

Article history:
Received 26 October 2013
Accepted 10 October 2014
Available online 7 November 2014

Keywords:
Landfills
Leachate treatment
Leachate chemistry
Principal components analysis
Regressions

ABSTRACT

A pilot-scale hybrid-passive treatment system operated at the Merrick Landfill in North Bay, Ontario, Canada, treats municipal landfill leachate and provides for subsequent natural attenuation. Collected leachate is directed to a hybrid-passive treatment system, followed by controlled release to a natural attenuation zone before entering the nearby Little Sturgeon River. The study presents a comprehensive evaluation of the performance of the system using multivariate statistical techniques to determine the interactions between parameters, major pollutants in the leachate, and the biological and chemical processes occurring in the system. Five parameters (ammonia, alkalinity, chemical oxygen demand (COD), "heavy" metals of interest, with atomic weights above calcium, and iron) were set as criteria for the evaluation of system performance based on their toxicity to aquatic ecosystems and importance in treatment with respect to discharge regulations. System data for a full range of water quality parameters over a 21-month period were analyzed using principal components analysis (PCA), as well as principal components (PC) and partial least squares (PLS) regressions. PCA indicated a high degree of association for most parameters with the first PC, which explained a high percentage (>40%) of the variation in the data, suggesting strong statistical relationships among most of the parameters in the system. Regression analyses identified 8 parameters (set as independent variables) that were most frequently retained for modeling the five criteria parameters (set as dependent variables), on a statistically significant level: conductivity, dissolved oxygen (DO), nitrite (NO_2^-), organic nitrogen (N), oxidation reduction potential (ORP), pH, sulfate and total volatile solids (TVS). The criteria parameters and the significant explanatory parameters were most important in modeling the dynamics of the passive treatment system during the study period. Such techniques and procedures were found to be highly valuable and could be applied to other sites to determine parameters of interest in similar naturalized engineered systems.

1. Introduction

Municipal Solid Waste (MSW) is a major concern for cities and communities around the world and presents a persistent management challenge. It is estimated that 1.3 billion tonnes of MSW is generated in cities around the world, and will only rise as urbanization continues (Hoornweg and Bhada-Tata, 2012). Landfill disposal still overwhelmingly remains the primary method for managing MSW in both high- and low-income countries, and brings with it the toxic by-product of landfill leachate. This wastewater is often composed of metals, organic matter, chlorinated chemicals, and high levels of nutrients (Speer et al., 2012). Due to the complexity of the solution and the high concentrations of individual pollutants, leachate treatment can be relatively expensive in terms of energy requirements and chemical inputs. Additionally, leachate production continues for many years after a landfill is closed, creating a long-term management burden for the operator (Mulamoottil et al., 1999; Rew and Mulamoottil, 1999). Landfill operators in low- and high-income countries can both benefit from sustainable treatment technologies that minimize the capital and operating costs of leachate treatment, while sufficiently treating effluents to minimize ecological impacts and human health risks.

Passive treatment systems are one such technology that can be operated effectively at a lower cost while performing comparably to more active and conventional systems. They have been successfully implemented at numerous facilities and are responsive to changing leachate composition and carry lower energy and

* Corresponding author. Tel.: +1 613 533 3053; fax: +1 613 533 2128.
E-mail addresses: jack.wallace@ce.queensu.ca (J. Wallace), champagne@civil.queensu.ca (P. Champagne), anne-charlotte.monnier@insa-lyon.fr (A.-C. Monnier).

http://dx.doi.org/10.1016/j.wasman.2014.10.011
0956-053X/

maintenance costs (Rew and Mulamoottil, 1999; Mehmood et al., 2009; Speer et al., 2012). An active treatment stage can be incorporated to improve performance in cold climates by providing a level of pre-treatment that removes a large fraction of the oxygen demand and metals (Speer, 2011), with the combined train termed a hybrid-passive treatment system. The complexity of the leachate necessitates the monitoring of a large number of water quality parameters to evaluate performance, where focused analyses can then be performed depending on the broad system dynamics. Multivariate statistical analysis is a useful set of techniques that can indicate interactions between variables and identify trends in treatment performance both spatially and temporally.

This study identifies the principal parameters affecting the performance of a novel hybrid-passive treatment system receiving leachate collected from an operating MSW landfill and providing for the controlled release of treated leachate to a natural attenuation zone prior to entering the receiving environment. The hybrid-passive system is considered novel due to the incorporation of dosing and rest cycles and active pre-treatment, and the evaluation of its performance in the challenging conditions of a cold northern climate, as reported by Speer et al. (2012). A comprehensive set of water quality parameters were monitored bi-weekly over a 21-month period, from December 2009 to August 2011. The data were analyzed using PCA, as well as PC and PLS regression analyses in order to understand the primary variables influencing system performance and the interactions and trends between them, with respect to treatment objectives that include minimizing the impacts of the treated leachate on the receiving environment. While these techniques have been applied to specific sets of parameters of interest, a principal objective of the study was to demonstrate the ability to identify and understand which parameters influence specific treatment targets or processes in naturalized, open systems such as the hybrid-passive system, through multivariate statistical analysis. Previous studies by Speer et al.

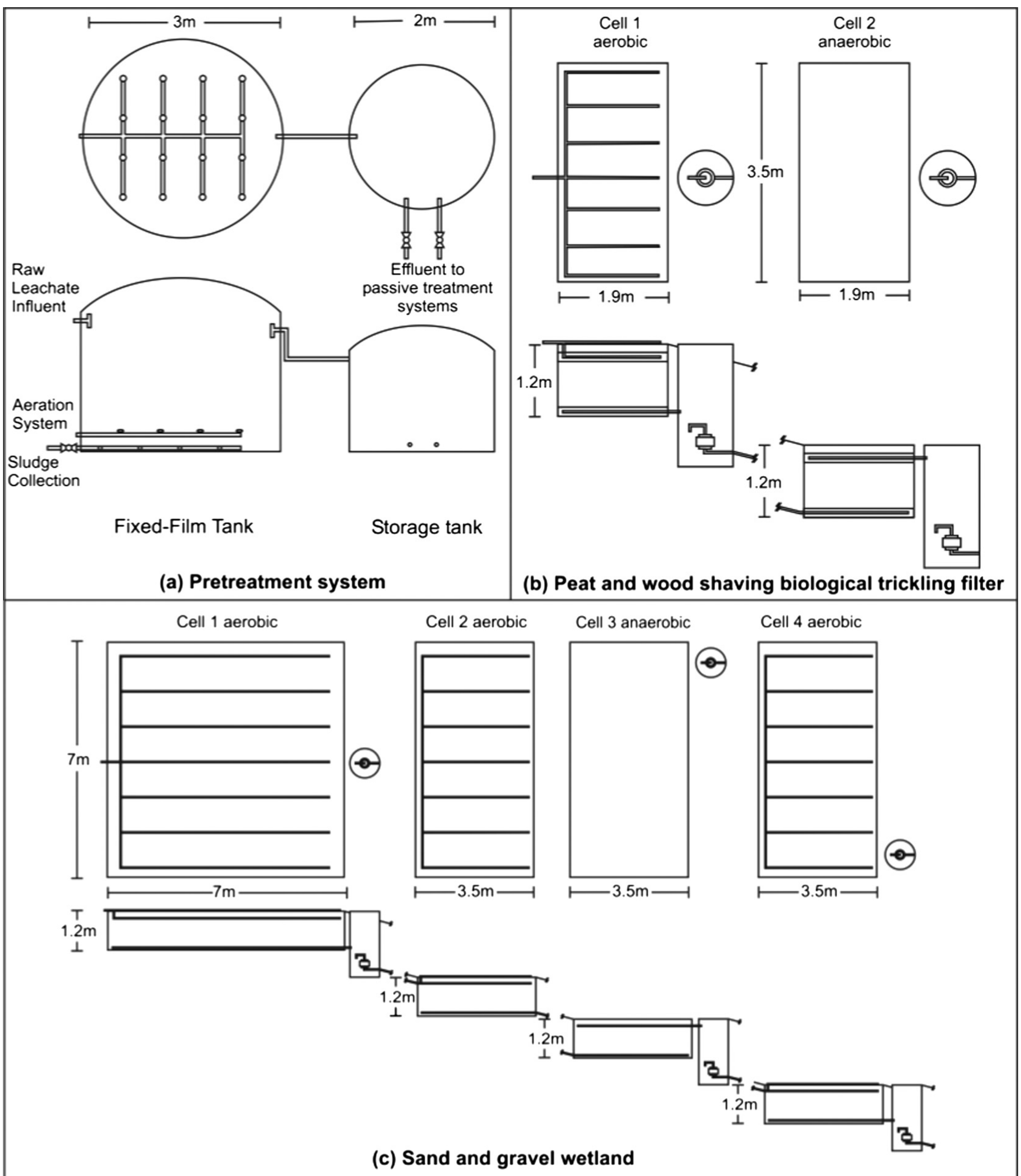

Fig. 1. Hybrid-passive treatment system schematic implemented at the Merrick Landfill in North Bay (Ontario, Canada) as designed and implemented by Speer (2011), with the configurations of the pre-treatment, PW, and AWL subsystems shown (Speer, 2011). Plan views are shown above side profile views for each component.