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Using fundamental hydrogeological equations to monitor the effects of clogging and media consolidation on the hydraulic regime of a vertical subsurface flow treatment system

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ABSTRACT

The design of passive biological filters has evolved and current design practices are predominantly based on flow (either horizontal or vertical) through porous media. To date, no method has been developed to accurately estimate the effective life expectancy of these types of treatment systems, nor have non-intrusive methods to determine the extent of substratum clogging been perfected. This research presents the results of tracer studies on various stages of two hybrid-passive landfill leachate treatment systems: an aerated pretreatment system followed by two different types of vertical-flow through porous media treatment systems. The tracer studies were used to assess changes in the active volumes of the different stages of the leachate treatment systems over a 9-month period. An analytical method, employing the governing equations for flow through porous media, was used to quantify the changes in saturated hydraulic conductivity in the treatment system cells. The results from the analytical method were combined with the results from the tracer study to further the understanding of the flow and mixing within the treatment system cells.

1. Introduction

Passive water treatment technologies – systems with relatively low maintenance and operational costs, requiring minimal energy and chemical inputs – have been used effectively to treat wastewater from various sources, ranging from easily biodegradable municipal wastewater to more recalcitrant industrial wastewater. A complete understanding of the design methods that will optimize the wastewater constituent removal within these systems is currently lacking, resulting in the use of mainly empirical system design methods (Forquet et al., 2009). Current research is aimed at developing a better understanding of the mechanisms of wastewater constituent removal in passive treatment systems. It is clear that removals are generally dependent on both hydraulic loading and retention (Faulwetter et al., 2009; Giraldi et al., 2009; Werner and Kadlec, 2000).

A number of passive treatment technologies are based on flow through porous media designs to allow for more effective biological treatment. The packing medium acts both as an attachment surface for microorganisms and a filtration material. Medium selection is an important design consideration for these systems, since the effectiveness of biological growth and solid filtration will affect the overall treatment efficiency. Biological growth and solids filtration will also affect the flow regime in the treatment system cell (Chazarenc et al., 2009; Zhao et al., 2009; Cooper, 2005). Clogging of the substratum as a result of biological growth can be reduced using aeration or by adopting a schedule of intermittent dosing allowing for passive aeration (Chazarenc et al., 2009). It is generally assumed that biological growth will be subject to a cycle of accumulation and sloughing which will maintain the extent of substratum clogging in a transient state. Pore spaces clogged with organic solids are eventually expected to return to functionality once degradation of the organic material has taken place. Inorganic precipitates that clog pore spaces can be detrimental to treatment system performance as they are not likely to be degraded or removed (Nivala et al., 2007; Maehlum, 1995).

Flow regimes within passive treatment systems can be evaluated using similar techniques as those employed to assess active treatment systems. Tracer studies are utilized to determine the retention times within the treatment system cells, as well as monitor the hydraulic regime and hydraulic efficiency. Intermittently dosed

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vertical flow passive treatment systems are difficult to analyze using conventional tracer techniques due to their inherent variable flow rates, which were shown to affect tracer response curves by Werner and Kadlec (2000), as well as the presence of both saturated and unsaturated zones in the treatment system cells (Giraldi et al., 2009). Conventional residence time distribution (RTD) analyses can be used to demonstrate the extent of global and local mixing within a treatment system cell. Giraldi et al. (2009) demonstrated that the water content in the system has a large effect on mixing and therefore the saturated zones can have a larger effect on overall mixing and the resultant tracer response curves. The use of tracer studies alone is therefore inadequate to determine changes in the unsaturated zone in these types of systems.

Clogging of pore spaces is one of the largest operational difficulties associated with the long-term use of passive treatment systems. It affects the flow regime, mixing and hydraulic residence time of the system. The rate of pore space clogging is a defining design parameter in terms of the effective lifecycle of a passive treatment system, as the packed media require maintenance or replacement at regular intervals to ensure treatment efficiency. The determination of the rate of clogging is important to the design process and, therefore, a method for monitoring the extent of clogging would be beneficial.

To date, non-intrusive methods for estimating the effects of substratum clogging and medium consolidation in passive treatment system cells have not been developed. By monitoring the influent and effluent flow profiles from the cells of the passive treatment systems, the governing equations for flow through porous media can be employed to estimate saturated hydraulic conductivities of these systems. In this study, these governing equations were applied to the influent and effluent flows measured during a 9-month monitoring study of two passive treatment systems treating landfill leachate in North Bay, Ontario, Canada. Changes in saturated hydraulic conductivities were estimated using the results obtained from this analytical solution, and were compared with the findings from tracer studies through the treatment system cells. The comparison of results was used to demonstrate which method would more adequately represent changes in the treatment system cells due to substratum clogging or medium consolidation.

2. Methods

2.1. Passive treatment systems

The primary difference in the design of the two passive treatment systems was the packing medium. The gravel wetland (WL) designed by Aqua Treatment Technologies™ was packed with 0.61 cm (1/4″) granular A gravel and consisted of four cells: WL1 designed for aerobic treatment (7 m wide, 7 m long, 1.2 m deep with a cross-section as shown in Fig. 1a), WL2 also designed for aerobic treatment (7 m wide, 3.5 m long, 1.2 m deep with a cross-section as shown in Fig. 1a), WL3 designed for anaerobic treatment (7 m wide, 3.5 m long, 1.2 m deep with a cross-section as shown in Fig. 1b), and WL4 designed for final aerobic polishing of the leachate (7 m wide, 3.5 m long, 1.2 m deep with a cross-section as shown in Fig. 1a). The peat and wood shaving biological trickle filter (PW) was packed with a mixture of peat and wood shavings at a ratio of 25:75 (v:v) and consisted of two cells: PW1 designed for aerobic treatment (3.5 m wide, 1.9 m long, 1.2 m deep with a cross-section as shown in Fig. 1a), and PW2 designed for anaerobic treatment (3.5 m wide, 1.9 m long, 1.2 m deep with a cross-section as shown in Fig. 1b). The treatment cells designed for aerobic treatment were constructed with two headers for leachate dosing; one header at the surface of the treatment system cell, and one located 30 cm (1 ft) below the treatment cell surface. The lower dosing manifold was designed for cold ambient temperature operation (September–April), to exploit the insulating capacity of the treatment cell packing medium.

Pretreated leachate was dosed to the first cells of the treatment systems (WL1 and PW1) using timer-controlled peristaltic pumps (ProMinent VF40 and VF32 respectively) to precisely dose each system (250 L dosed 8 times per day at a rate of 83 L/min to WL1 and 333 L dosed 6 times per day at a rate of 48 L/min to PW1). Leachate dosing between the cells of the treatment systems was achieved using dosing siphons (from Fluid Dynamics Siphons Inc.). The effluents from WL1, WL3, PW1 and PW2 were captured in siphon chambers, in which outflow rates were monitored using Levelloggers™. Leachate was intermittently dosed to the subsequent cells as siphon events were triggered (peak flow rates from each siphon chamber are presented in Table 1). Cell WL3 was designed as an up-flow anaerobic cell, and the leachate was allowed to flow directly from WL2 to WL3 without a siphon chamber.

2.2. Tracer studies

A single-event tracer study was conducted every three months to characterize the change in the active volumes of the passive treatment system cells as the systems matured. The passive treatment systems were separated into distinct treatment cells for tracer analysis. A lithium chloride tracer was introduced to each of the treatment system cells concurrent with a leachate-dosing event at a concentration of 100 mg of lithium/L (assuming complete mixing of the tracer solution with the dosed leachate volume – 250 L volume to the WL cells and 333 L to the PW cells). To achieve this, 20 L of concentrated tracer solution (1350 mg of lithium/L for the WL cells and 1765 mg of lithium/L for the PW cells) was injected into the pipes directly following the peristaltic pumps (dosing cells WL1 and PW1) or the siphons (dosing WL2 and PW2). Tracer solutions were

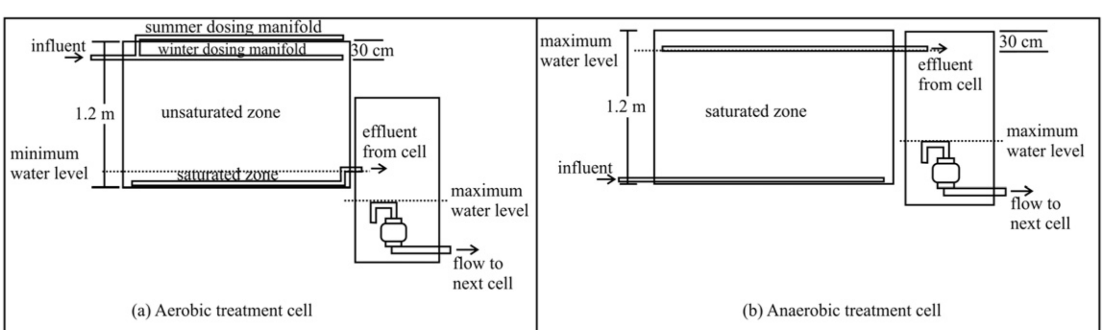

Fig. 1. Schematic of treatment system cell designs. (a) Aerobic and (b) anaerobic.