Science of the Total Environment 633 (2018) 145–156

Contents lists available at ScienceDirect

Science of the Total Environment

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

Understanding intricacies of clogging and its alleviation by introducing earthworms in soil biofilters

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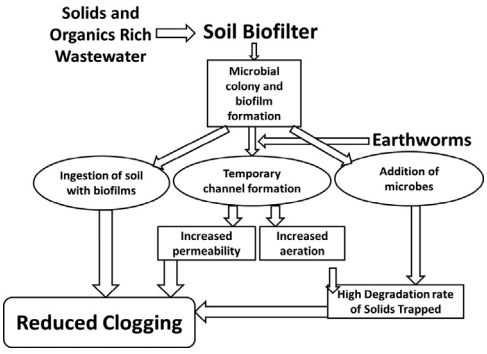
HIGHLIGHTS

- Clogging increases with the increase in organic strength of the influent.
- Earthworms decrease the rate of clogging in soil biofilter.
- Earthworms maintain requisite dissolved oxygen in soil biofilter.
- Hydraulic permeability increases with the introduction of earthworms.
- Earthworm's introduction into biofilter reduces nutrient contents in the effluent.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 January 2018
Received in revised form 13 March 2018
Accepted 15 March 2018
Available online xxxx

Editor: Frederic Coulon

Keywords:
Eisenia fetida
Hydraulic conductivity
Head loss
Organics
Nutrients

ABSTRACT

With the scarcity of fresh water and rise in pollution load in the aquatic ecosystem over the globe, the domestic and industrial effluents need to be reused after suitable treatment. In an attempt to do so, soil biofilters have been identified as a treatment alternative that is suitable for application in developing countries. However, rapid development of clogging in the soil biofilters limits its applicability as an effective technology. This paper aims to understand the occurrence of clogging due to biofilms formation in and over the bedding of soil media. To address this, the organic loading rates (OLRs) were varied in the range of 2.25–11.25 kgCOD/m^3·day to create different degree of clogging. Earthworms were inoculated into the soil bedding at the earthworm densities (EWDs) of 0, 5000 and 10,000 earthworms/m^3 to study the effect of earthworms introduction on clogging. The degree of clogging was measured using clogging coefficient (CC), hydraulic conductivity and head loss. The study highlights the impact of earthworms on the removal performance and clogging of soil biofilter. For all earthworm densities, head loss and clogging coefficient increased and hydraulic conductivity decreased linearly with organic loading rate. Introduction of earthworms versus no earthworms resulted in lower head loss and clogging coefficient and higher hydraulic conductivity for all organic loading rates, while increasing EWD from 5000 to 10,000 had only marginal effects on all parameters. The study reveals that high organic loading rate activates higher number of microbial sites, in turn causing higher degree of clogging. However, the introduction of earthworms reduces the clogging rate significantly along with enhanced treatment performance. The outcome of this study indicates that incorporation of earthworms into the soil biofilter can reduce the degree of bio-clogging and might provide a highly sustainable, low cost and efficient treatment system for the developing countries.

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https://doi.org/10.1016/j.scitotenv.2018.03.156
0048-9697/

1. Introduction

Breweries are the most water demanding industries and in general, are frequently situated in regions hit by water scarcity. From brewing process to the final bottling of the product, it takes high amount of water to make beer. Typically for preparing a liter of beer, 3–10 L of water gets wasted in its miscellaneous operations based on its operational practices (Simate et al., 2011). Such high consumption of wastewater creates an artificial scarcity of water that in turn gives birth to the depletion of water resources. On the other hand, the water scarcity further forces the brewery owners to consider ways to reuse the water in the chores, which demand low quality water. Moreover, the detrimental impact of brewery effluent is not limited to the above stated only, as the discharge from breweries adds many pollutants to the water bodies, such as organics, nutrients and solids. The hostile impact of the pollutant introduction further leads to the emergence of many uncomplimentary conditions such as eutrophication, blue baby syndrome caused by methaemoglobinaemia, destruction of aquatic flora and fauna, etc. Dominance of such conditions in the existing water bodies further stresses the need to develop reliable technologies treating wastewaters for further reuse or flushing to public sewers.

With the aim to treat effluent from breweries, many attempts have already been undertaken and some of the attempts have yielded very appealing results. However, the existing technologies have their own set of limitations, chiefly; high cost, need for skilled labor and by-product generation. For instance, physical methods yield incomplete removals, whereas chemical methods require highly skilled labor, investment and generate by-product. The biological methods employed to treat brewery effluents also have their own set of limitations. For example, the anaerobic technologies require high start-up time and are highly susceptible to the changes in the parameters, such as temperature and pH. Whereas, aerobic methods yield high removals, but require high energy and floor space area to keep the system aerated. Additionally, the aerobic methods generate a huge quantum of sludge that becomes another serious concern (Metcalf and Eddy, 1991). After evaluating all possible aspects related to the existing treatment technologies, it was felt that the need of the hour is to find a new solution that is not only highly efficient and economical but also generates no harmful by-products requiring further care from pollution perspectives.

Considering the above, filters made of soil as media were considered, which need no such high capital investment as it is mostly composed of natural locally available ingredients. However, the organics removal from biofilter is moderate and the nutrient removals (nitrogen and phosphorous) are not considerable. Another major predicament with the biofilter is its progressive clogging due to the organic and solids loading (Sinha et al., 2008). The impact of solids loading on clogging is constantly being investigated, but, so far no significant efforts have been specified to establish an understanding on the impact of organics on the degree of clogging.

Formation of clogging can be identified by the inundation of bed or water near the zone that receives influent (Grace et al., 2016). In case of extreme clogging, inundation over the whole bed may also develop. The clogging in systems is reported to occur chiefly because of the blocking of micro pores due to the formation of microbial colonies and substrate deposition (Blazejewski and Murat-Blazejewska, 1997; Tanner et al., 1998; Sun et al., 1999; Nguyen, 2000). In addition, the irreversible nature of clogging and the continuous input of organics and solids is supposed to accelerate the deposition and worsen the filter condition. The worsening of conditions inside the filter might further lead the system to lack dissolved oxygen (DO) in the pores, forming an adverse environment (Platzer and Mauch, 1997; Zhao et al., 2004). The unfavorable environment inside the bedding might further result in anaerobic conditions, which in turn may develop obnoxious odors and an unaesthetic ambience. Additionally, even though the impact of clogging is primarily related to the hydraulic characteristics of any system, in extreme cases it may also cause a shift in the population and diversity of microbes. The transport of dissolved oxygen (DO) through the bed is supposed to be negatively impacted by clogging and thus reduces the treatment potential. The clogging of any system can also become a major factor in decreasing its lifespan (Singh et al., 2017).

Henceforth, there is an immediate need to understand the aspects related to clogging in biofilter, which could help in prolonging the life span. In view of the above, more in-depth studies are necessary towards developing a better understanding of clogging, mechanisms involved in clogging and its impact on biofiltration. Many studies are presently being carried out to analyze and quantify the extent of clogging in other conventional treatment technologies such as in constructed wetlands and sand filter (Nivala et al., 2012). However, clogging is a complicated process and still there is no direct measure to quantify the degree of clogging. As far as the restoration/removal of clogging is concerned, it can be done by i) washing the clogged bed (Murphy et al., 2009) ii) replacing the filter beds (Wallace and Knight, 2006) iii) exposing it to the chemical agents (Hua et al., 2010; Nivala and Rousseau, 2009). Methods involved in restoration of clogging are however costly and might need another 3–4 weeks of acclimatization (Pedescoll et al., 2009). Owing to the above limitations in restoration, further researches are now required to find alternatives to reverse the clogging.

After analysis of clogging reversal in constructed wetlands (Li et al., 2011), it can be concluded that introduction of earthworms into the biofilters can help in delaying the clogging. Biofilters with earthworms are termed as vermifilter or earthworm assisted eco-microbial filters. Earthworms in soil biofilters are found to be efficient in removing pollutants (Sinha et al., 2008). The application of vermifilter in wastewater treatment is increasingly becoming popular (Jiang et al., 2016; Singh et al., 2017). In recent years, many researches are coming up to understand every aspects such as earthworm species, HLR, etc. (Kumar et al., 2014; Kumar et al., 2016). The rise in its implementation can be attributed to the low requirement of investment, as the system is composed of naturally abundant materials such as soil, earthworms, sand and gravel. In addition, the gravity fed vermifilters can be run without involving any technical labor and energy. The vermifiltration produces organic compost as soil probiotic and earthworm biomass, which can further be utilized in operations such as horticulture and fish feeding, respectively.

Despite having many benefits over the existing treatment technologies, vermifilter also experience clogging as an operational problem, that may restrict its application as an efficient and cost-effective technology (Singh et al., 2017; Samal et al., 2017). Up to date, no studies are available to quantify the degree of clogging in vermifilters. In addition, the combined impact of clogging and earthworms on removal of pollutants of common interests is also not addressed. This is where our study starts. We attempt to develop an understanding of the clogging mechanism by quantifying clogging by microbial colonies in vermifilters subjected to different organic loading rates (OLRs). This is a new contribution as the previous researches were mostly limited to the development of clogging due to deposition of suspended solids only. In a second step, we aim to mitigate clogging and therefore low removal efficiency from the biofilters by introducing earthworms into the filter bed. In particular, the effect of earthworm introduction on the degree of clogging and pollutants removal is addressed.

2. Material and methods

2.1. Experimental influent

The synthetic brewery wastewater used in this study was produced according to Mata et al. (2012) by using tap water having DO of 4–5 mg/L. Synthetic wastewaters were prepared and fed under gravity to the reactors in order to maintain the desired loadings according to Table 1. The constituents used in the preparation of wastewater were peptone, malt extract, maltose, yeast extract, and ethanol. As inorganic nutrients ammonium sulphate, monosodium phosphate and disodium