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Effect of organic load on phosphorus and bacteria removal from wastewater using alkaline filter materials

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ABSTRACT

The organic matter released from septic tanks can disturb the subsequent step in on-site wastewater treatment such as the innovative filters for phosphorus removal. This study investigated the effect of organic load on phosphorus (P) and bacteria removal by reactive filter materials under real-life treatment conditions. Two long-term column experiments were conducted at very short hydraulic residence times (average ~5.5 h), using wastewater with high (mean ~120 mg L^{-1}) and low (mean ~20 mg L^{-1}) BOD_7 values. Two alkaline filter materials, the calcium-silicate material Polonite and blast furnace slag (BFS), were tested for the removal capacity of total P, total organic carbon (TOC) and Enterococci. Both experiments showed that Polonite removed P significantly ($p < 0.01$) better than BFS. An increase in P removal efficiency of 29.3% was observed for the Polonite filter at the lower concentration of BOD_7 ($p < 0.05$). Polonite was also better than BFS with regard to removal of TOC, but there were no significant differences between the two filter materials with regard to removal of Enterococci. The reduction in Enterococci was greater in the experiment using wastewater with high BOD_7, an effect attributable to the higher concentration of bacteria in that wastewater. Overall, the results demonstrate the importance of extensive pre-treatment of wastewater to achieve good phosphorus removal in reactive bed filters and prolonged filter life.

1. Introduction

On-site wastewater treatment is generally based on natural soil infiltration systems, which are reported to exhibit acceptable purification performance with respect to organics, nutrients and bacteria (Beal et al., 2005). However, this technology has recently been questioned in terms of aspects such as phosphorus (P) removal efficiency and sustainability (Eveborn et al., 2012). Some studies also indicate that soil infiltration systems may pose a bacterial pollution risk to

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groundwater (Stevik et al., 1999). Therefore, on-site filter systems based on specially engineered media have been developed with the aim of removing P from residential wastewaters in rural areas (Renman and Renman, 2010; Drizo, 2012). Extensive research world-wide on different filter materials has confirmed their efficiency in P removal. Comprehensive reviews of suitable filter materials are provided by Johansson Westholm (2006) and, more recently, by Vohla et al. (2011). Some mineral-based and alkaline filter materials have been tested in field trials with real-life wastewater. A few have shown promising results and are now commercially available in Sweden (Renman and Renman, 2010), Norway (Jenssen et al., 2010) and the US (Drizo, 2012), where they are used in small-scale treatment facilities serving single houses or groups of houses.

The main purpose of using alkaline filter materials is to remove P from wastewater to concentrations that comply with statutory effluent criteria such as those applied in Sweden for on-site wastewater treatment (total $P < 1$ mg L^{-1} or 70–90% removal) (SEPA, 2008). The alkaline conditions (pH 8–12) also bring about a reduction in bacteria. Conventional soil infiltration systems use sand and rely on physical filtration, straining and adsorption as the main removal mechanisms, with the clogging zone near the infiltration surface playing an important role for bacteria removal (Stevik et al., 1999; Chabaud et al., 2006). In contrast to sand filters, most alkaline filter materials have a coarse, porous structure with high hydraulic conductivity and are operated under saturated flow. Therefore an efficient pre-treatment prior to filtration is suggested to be a necessity to avoid biofilm development and clogging. Organic load, including bacteria, could prevent the removal of P by the filter material, thus reducing its lifetime considerably. Laboratory experiments (Alvarez et al., 2004) have shown that the presence of organic ligands inhibits the precipitation of calcium phosphates, one of the principal mechanisms for P removal in the commercial products Polonite and blast furnace slag (BFS) (Gustafsson et al., 2008).

Contamination of groundwater by on-site wastewater containing pathogenic microorganisms, particularly enteric viruses, has long been reported (Craun, 1985). Contamination of surface water is also common and might involve a human health risk. It is therefore important that the wastewater treatment systems include the immobilization of microorganisms. Furthermore, since the filter materials are intended for recycling to crop production (Cucarella et al., 2012), a product with minimal bacteria content would be of great benefit. A suitable group of bacteria for use as an indicator of contamination are the faecal streptococci, in which the genus *Enterococcus* is a sub-group (Ausland et al. 2002). Enterococci are Gram-positive, facultative anaerobic bacteria that can grow in a wide range of temperatures and withstand freezing and high pH values (Fisher and Phillips, 2009). It is proposed in Sweden that Enterococci can be used as indicator organisms when returning P through wastewater treatment products back to agriculture (SEPA, 2002).

In Sweden, filter traps are constructed primarily for P removal and recycling (Cucarella, 2009; Renman and Renman, 2010). The operation of several full-scale systems shows that the gradual decline in pH that occurs over time, is correlated with a decrease in P removal efficiency. However, there is also reason to suspect a corresponding effect of organic load, which can vary significantly depending on the pre-treatment system used. Hence it is important to investigate the effects of organic matter on the P removal process and how it affects filter longevity. Bird and Drizo (2010) showed that P removal efficiency and filter life were significantly higher in steel slag filters fed with agricultural effluent with lower organic matter content than domestic sewage.

The aim of this study was therefore to investigate the removal capacity of two filter materials for bacteria (i.e. Enterococci), total organic carbon (TOC) and P in relation to two different loads of organic matter. This was studied in a long-term (duration from 84 up to 136 days) dynamic column experiment using on-site wastewater under real-life treatment conditions.

2. Materials and methods

2.1. Materials

2.1.1. Filter materials – chemical and physical properties

Two different filter materials were used for the investigation, blast furnace slag (BFS) and Polonite (Table 1). The element analysis of the filter materials was performed by ALS Scandinavia AB, Luleå, Sweden, using simultaneous ICP-OES (ARL, model 3560, Thermo Scientific). Radiometer PHM 82 Standard pH-meter was used for determining pH in 100 mL of influent and effluent samples. The pH of filter materials was determined at 1:2.5 (w:V) soil:distilled water suspension after 24 h contact. Density of the materials was determined by the pycnometer method and porosity was calculated from the fluid porosity method. Measurement of the saturated hydraulic conductivity was performed using a permeameter according to the falling head method.

BFS is a by-product from the steel-making industry. Polonite is a manufactured product, prepared from the porous bedrock opoka. Both filter materials are characterised by high contents of calcium (Ca) and silicon (Si) (Table 1). See Renman (2008) for a more detailed description of the materials. For

Table 1 – Chemical and physical properties of blast furnace slag (BFS) and Polonite.

Parameter	BFS	Polonite
Si (g kg^{-1})	155	241
Al (g kg^{-1})	69.7	27
Ca (g kg^{-1})	216	245
Fe (g kg^{-1})	3.11	16.5
K (g kg^{-1})	6.18	9.15
Mg (g kg^{-1})	97.6	4.4
Mn (g kg^{-1})	4.69	0.12
Na (g kg^{-1})	4.28	1.46
P (g kg^{-1})	<0.1	0.34
pH	9.7–10.0	11.2–12.3
Density (g cm^{-3})	2.2	0.8
Porosity (%)	28	43
Hydraulic conductivity (m day^{-1})	255	800
Particle size (mm)	0.5–4	2–6