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Performance study of biofilter system for on-site greywater treatment at cottages and small households

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ABSTRACT

The current contribution of microbial pathogens and nutrient discharge into the environment from inefficient on-site wastewater treatment systems has raised concern in many areas due to the pollution of the nearby water recipient. To overcome this challenge, a novel and more robust proven treatment systems are required. This paper aims to assess the performance of a source separating wastewater management system for the removal of organic matter, total P, total suspended particles and *E. coli*. The system is a multi-stage approach including – a separate collection of blackwater (BW) and greywater, followed by on-site greywater treatment system in a fixed-film biofilter and finally a soil infiltration system used as a polishing step before discharging into the environment. The separation and collection of BW resulted a notable reduction for chemical oxidation demand (COD), biochemical oxidation demand (BOD), total suspended solids (TSS), nitrogen (N) and phosphorus (P) accounting for 64%, 61%, 75%, 85 and 88%, respectively. The overall removal efficiency of the system for the above-mentioned parameters reached over 90% at the biofilter effluent and more than 95% at the bottom of the constructed infiltration column. For coliform bacteria and *E. coli*, the overall system reached a reduction of 4–5 $\log_{10}$ units of which the major reduction was observed in the infiltration columns. The effluent quality from this source-separating and multi-barrier biofilter treatment system complies with the Norwegian discharge limits. The assessment results reveal that this system can be used in drinking water source catchments with minimum environmental and health related risks.

1. Introduction

The European water directive regulates treatment and discharge of wastewater based on the eutrophication sensitivity of the watersheds within a particular area. While greater efforts have been taken on the improvement of centralized wastewater systems in urban centers, little attention was so far given to rural areas, which are accounting for a notable fraction of the total wastewater production, especially in the northern countries. Based on statistics from 2015 (Berge and Chaudhary, 2015), 16% of the Norwegian population are not connected to central sewerage systems. Likewise, about one million residents in Finland, 20% of the total population, and over one million vacationists lives in houses that are not connected to the municipal sewer network (Lehtoranta et al., 2014). In addition to the 330,000 on-site systems for rural residents, more than 420,000 recreational houses are currently found in rural Norway (SSB, 2016) with the result that none-severed rural areas contribute with 24% of the wastewater production in the country. In 2014, the estimated nutrient discharges from rural households were approximately 350 tons for phosphorus and 3010 tons for nitrogen (Berge and Chaudhary, 2015) which is a significant fraction to affect the recipient water sources. Similar trend was also observed in Finland (Lehtoranta et al., 2014). In addition to eutrophication effects, on-site wastewater systems may pose a health risk to consumers of drinking water by spreading of pathogens to raw water catchments or by direct contamination of local wells. Hence rural wastewater management needs to be improved in order to sustain or improve the environmental quality and to protect human health.

Especially recreational houses that increased substantially both in number and size as well as in standard of sanitary facilities contributes with an increasing challenges in terms to rural wastewater management (Kaltenborn et al., 2009; Rye and Berg, 2011). Geological conditions on high mountain areas, where a majority of the cottages are located, often limit the applicability of soil infiltra-

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tion, which is the dominant type of wastewater treatment (29%) in rural Norway (SSB, 2016). On particular places package treatment plants were installed as an alternative, but these systems were also shown to struggle with the highly varying loading conditions and limited maintenance, resulting into frequent malfunction periods with high discharge of pollutants (Schwemer and Wolfgang, 2016). Novel and more robust wastewater treatment systems need therefore to be developed to handle the increasing environmental pollution from Norwegian recreation homes.

Source separating sanitation was pointed out as a potential solution to meet the challenges in rural and recreational wastewater management (Jenssen et al., 2016). In this approach, only the so called greywater originated from kitchen and washing facilities is treated locally while the notably higher polluted blackwater originated from toilets is collected and transported to a centralized treatment or recovery facility. Many different kinds of on-site wastewater and particularly greywater treatment systems have been developed and tested worldwide. Moreover, in countries like the USA and Australia, where regulations for the use of GW have been well established based on issues associated with public health and potential environmental impact, GW treatment for non-potable use is highly encouraged (Oron et al., 2014). However, the bulk of small-scale GW treatment systems currently proposed are either simple filtration systems providing minimal treatment, or are treatment systems, which are not designed to handle the differences in both flow and composition and are therefore not suitable (Gross et al., 2007). Others are complex treatment processes incorporating sedimentation tanks, bioreactors, ultra- and nano-membrane filtration, coagulants, and direct disinfection, which are more costly in terms of energy, operation and maintenance.

A multi-stage process consisting of several partially redundant treatment steps in series offer a relatively high treatment stability despite the variable loading rate. At present only little data are available on such source separating sanitary systems and these are mainly gathered from larger-scale pilot installations in urban regions (Todt et al., 2015). This study performed a comprehensive experiment to assess treatment efficiencies and effluent quality for each particular treatment step in a rural configuration of a source separating sanitary system. Post treatment system using column filtration to mimic soil infiltration trench was carried out to study the application in vulnerable areas and where discharge requirements are very stringent.

2. Methods

2.1. Source separating sanitary system

This study was done with greywater (GW) and blackwater (BW) supplied by a student dormitory with 48 inhabitants. The BW collected with vacuum toilets having a flushing volume of 1.2 l and the greywater is collected and pumped separately into two separate stirred storage tanks in the laboratory. More details are given in Todt et al. (2015). For both wastewater fractions (GW, BW), grab samples were taken from the particular stirred storage tank. The concentration in a putative mixed raw sewage (C_{raw}) was calculated considering an average BW fraction of 5.5% on the total wastewater volume as determined by Todt et al. (2015). This calculation was done with help of random variable algebra considering the measured concentrations ranges for greywater (C_{GW}) and blackwater (C_{BW}) as normal (COD, BOD, TSS, P) or log-normal (Coliform bacteria) distributed random variables, while a constant value was taken for the volume fraction of blackwater (f_{BW}) to avoid ratio distribution (Eq. (1))

$$C_{raw}(\mu,\sigma) = C_{GW}(\mu,\sigma) * (1 - f_{BW}) + C_{BW}(\mu,\sigma) * f_{BW} \quad (1)$$

Table 1
Diurnal distribution of greywater into the GWTP.

Time frame	Volume fraction (%)
0:00–07:00	no load
07:00–09:00	40
09:00–12:00	15
12:00–19:00	no load
19:00–21:00	30
21:00–0:00	15

2.2. Greywater treatment system

The study used a greywater treatment GWT system (Ecomotive A02, Ecomotive AS, Runde, Norway) designed for cottages and small households (Heistad, 2008). The GWT system encompasses a sequence of a primary settler, an unsaturated fixed-film biofilter and a secondary clarifier. For the fixed film biofilter lightweight clay aggregates having a diameter of 10–20 mm (LWA) (Filtralite, Saint-Gobain Byggevarer AS, Alnabru, Norway) is used. The filter bed has a thickness of 500 mm. After primary settling, the greywater is distributed over the biofilter in intermittent pulses via full cone nozzles as described in Heistad (2008). The dosing pump was controlled by a level switch in the primary settler and a timer giving the pulse intervals. The filter is designed for a nominal load of 650 l d^{-1}, which results into a surface load of 282 mm d^{-1}. The biofilter is supposed to serve for a longer period, but to sustain its efficiency, a resting period of two or three weeks in a year is required.

The GWT system was loaded based the European test protocol for package treatment plants (NS-EN 12566-3:2005 + A2:2013) with a diurnal distribution of hydraulic load (Table 1). Feeding of the GWTP was performed with a peristaltic pump (Bredel SPX, Watson Marlos, Falmouth, UK) and hydraulic load was monitored with a flow meter (Optiflux2000, Krohne, Duisburg, Germany). Grab samples were taken from the effluent of the secondary clarifier. The power consumption was monitored with a power meter connected to the 230 V AC supply of the GWTP.

The data from the GWTP were collected from April 2013 to Mai 2016. In total, the system was in operation for 458 days in four continuous periods lasting from 28 to 223 days related to different experiments and performance tests that were conducted with the system. The latter included different sequences with overload, underload and simulated power breaks as outlined more in detail in Table 2.

2.3. Infiltration trench as a polishing step for the GWTP effluent

To gather more data on the recommended post polishing in an infiltration trench, a column experiment was establish (Reiakvam, 2016). During this period, the GWTP was operated with nominal load. The experiment encompassed two parallel columns having a diameter of 600 mm. Each column represents a discharge point in an infiltration trench with a single-hole in the perforated disposal pipe that is placed on the top of the infiltration trench in the actual disposal system. The infiltration material used in this experiment consists of 150 mm drainage layer of 11–22 mm crushed granite stone at the bottom and sequentially overlaid by 150 mm of 0.2-1.0 mm fine sand dominated by silicon dioxide in the form of quartz and 150 mm of 2–4 mm LWA (Filtralite, Saint-Gobain Byggevarer AS, Alnabru, Norway). Single geotextile cover separated the layers and the trench is covered with 200 mm of till soil (sandy loam) at the top to mimic backfill (Fig. 1). Each of the infiltration columns was loaded with GWTP effluent with peristaltic pumps at an actual flow rate of 2.5 l h^{-1}. The infiltration took place via a pipe having 6 mm inner diameter to the center of the column on the top of the LWA layer, giving a total filtration depth of 450 mm (Fig. 2). Loading of the