Journal of Urban and Environmental Engineering, v.8, n.1 p. 89-97, 2014

ISSN 1982-3932
doi: 10.4090/juee.2014.v8n1.089097

Journal of Urban and Environmental Engineering

www.journal-uee.org

REVIEW ON NATURAL METHODS FOR WASTE WATER TREATMENT

Ashwani Kumar Dubey* and Omprakash Sahu

Department of Chemical Engineering, KIOT, Wollo University, Ethiopia

Received 20 October 2013; received in revised form 20 December 2013; accepted 18 March 2014

Abstract: In Ethiopia, the most common method of disposal of waste water is by land spreading. This treatment method has numerous problems, namely high labor requirements and the potential for eutrophication of surface and ground waters. Constructed wetlands are commonly used for treatment of secondary municipal wastewaters and they have been gaining popularity for treatment of agricultural wastewaters in Ethiopia. Intermittent sand filtration may offer an alternative to traditional treatment methods. As well as providing comparable treatment performance, they also have a smaller footprint, due to the substantially higher organic loading rates that may be applied to their surfaces. This paper discusses the performance and design criteria of constructed wetlands for the treatment of domestic and agricultural wastewater, and sand filters for the treatment of domestic wastewater. It also proposes sand filtration as an alternative treatment mechanism for agricultural wastewater and suggests design guidelines.

Keywords: domestic wastewater; intermittent sand filtration; constructed wetlands; land spreading; organic loading rate.

* Correspondence to: Omprakash Sahu, Tel.: +251933520653
E-mail: ops0121@gmail.com

INTRODUCTION

Waste water treatment is big issue now days due to high cost of equipment and chemical. As well as some time it cannot be reduced the pollutant like heavy metal or contain nitrogen up to the required limit. Due untreated water affect the social (health) and nature (soil, flora and fauna) life. Especially when soil is polluted it affects all the system. It is due to spreading of untreated runaway and leachates. In land spreading on free-draining soils, the main nutrient removal processes are filtration, soil adsorption, microbial decomposition, and plant uptake. The latter two processes are active in reducing nitrate-nitrogen (NO3-N) concentrations; however, if NO3-N passes beyond the root zone it can be leached to the groundwater. Analyses of five Irish borehole (well) waters underlying light textured soils receiving high nitrogen (N) applications have yielded NO3-N concentrations greater than the EU maximum allowable concentration (MAC) of 11.3 mg L^{-1} for drinking water (Richards *et al.*, 1998). In that study, Richards *et al.* (1998) found, that in a plot comprising a sand loam overlying a sandy silt loam to 106 cm deep receiving a mean wastewater application rate of 677 kg N ha^{-1} $year^{-1}$, mainly as organic N, soil water NO3-N concentration was 23 mg NO3-N L^{-1}. The Nitrate Directive, 91/676/EEC (EEC, 1991) has focused considerable attention on the disposal of agricultural wastewaters in Ethiopia, where about 25% of the land area is devoted to dairy farming (Carton, 2001). A survey of 1132 rivers and streams from 2001 to 2003 (Toner *et al.*, 2005) estimated that the percentage of pollution attributed to agriculture was approximately 32%, 32% and 15% in rivers and streams which were slightly, moderately, and seriously polluted, respectively.

In recent years, the use of constructed wetlands (CWs) for the waste water treatment has been gaining popularity, due to their relatively low capital costs and maintenance requirements. However, intermittent sand filtration (ISF) may have the potential to treat waste water effectively and, where denitrification is incorporated, to reduce NO3-N to low levels. To date, the use of ISF for the treatment of agricultural wastewater has been limited. They have been used in the dewatering of swine wastewater following addition of organic polymers to increase settlement of suspended solids (SS) and organic compounds (Vanotti *et al.*, 2005; Szogi *et al.*, 2006) and in the treatment of detergent and milk fat wastewaters (Liu *et al.*, 1998; Liu et al, 2000; Liu *et al.*, 2003). In this regard's an effort has been made to discuss the importance of wetland and sand filter to treat the waste water.

DOMESTIC WASTEWATER TREATMENT

Constructed Wetlands

There are two types of CW: free water surface constructed wetlands (FWS CWs) and subsurface CWs. In FWS CWs, wastewater flows in a shallow water layer over a soil substrate. Subsurface CWs may be either subsurface horizontal flow CWs (SSHF CWs) or subsurface vertical flow CWs (SSVF CWs). In SSHF CWs, wastewater flows horizontally through the substrate. In SSVF CWs, wastewater is dosed intermittently onto the surface of sand and gravel filters and gradually drains through the filter media before collecting in a drain at the base. CWs may be planted with a mixture of submerged, emergent and, in the case of FWS CWs, floating vegetation. The large surface area of CWs provides an environment for the physical/physico-chemical retention and biological reduction of organic matter and nutrients (Geary & Moore, 1999; Knight *et al.*, 2000). Depending on the type of CW used, its design, organic loading rate and hydraulic retention time (HRT) (Karpiscak *et al.*, 1999), a CW can have a significant nutrient removal capability. However, due to the effect of changing temperatures, the treatment efficiency of these systems tends to change throughout the year (Bachand & Horne, 2000; Healy & Cawley, 2002).

Although temperature affects the performance of FWS CWs, SSHF CWs and SSVF CWs, they generally meet relevant effluent discharge criteria in colder climates (Maehlum *et al.*, 1995; Vymazal, 2002; Rousseau *et al.*, 2004). In Europe, effluent BOD_5 and SS standards for discharge into surface waters range from 250 mg BOD_5 L^{-1} in the Ethiopia to 25 mg BOD_5 L^{-1} in Austria and 70 mg SS L^{-1} in The Ethiopia to 35 mg SS L^{-1} in the Czech Republic, respectively (Rousseau *et al.*, 2004). In Norway, where mean winter temperatures can drop below -10^{o}C, Maehlum *et al.* (1995) used an SSHF CW to treat septic tank wastewater. Under an organic loading rate of approximately 4 g BOD_5 m^{-2} d^{-1}, BOD_5 and Tot-N was removed by 93% and 48%, respectively **(Table 1)**.

N removal in CWs is accomplished primarily by physical settlement, denitrification and plant/microbial uptake. Plant uptake does not represent permanent removal unless plants are routinely harvested. Phosphorus (P) is removed through short-term or long-term storage. Uptake by bacteria, algae and duckweed (Lemma *spp.*), and macrophytes provides an initial removal mechanism (Kadlec, 1997). However, this is only a short-term P storage as 35−75 % of P stored is eventually released back into the water upon dieback of algae and microbes (Richardson & Craft, 1993; White *et al.*, 2000). Anaerobic conditions which exist at the soil/water interface may also cause the release of P back into the water column (Patrick & Khald, 1974). The only long-term P storage in the wetland is via peat accumulation and substrate fixation. The efficiency of long-term peat storage is a function of the loading rate and also depends on the amount of native iron, calcium, aluminium, and organic matter in the substrate (Shatwell & Cordery, 1999). Lake and reservoir sediments have been shown to act as P sinks (Richardson & Craft, 1993; White *et al.*, 2000). At P loading rates of less than 5 g P m^{-2} $year^{-1}$, wetland sediment can absorb greater than 90% of the total incoming P (Faulkner & Richardson, 1989).

Pre-treatment Domestic wastewater must undergo septic tank pre-treatment prior to entering a CW (EPA, 2000). In municipal wastewater treatment, an activated sludge plant provides initial settlement, organic carbon removal and partial nitrification (Healy & Cawley, 2002). To protect against groundwater contamination, all FWS CWs, SSHF and SSVF CWs should be lined with an impervious layer, *e.g.*, a high density polyethylene liner (HDPL).

Media selection For FWS CWs, a substrate rich in iron, calcium and aluminium is recommended. For SSHF CWs, a soil or gravel is recommended (Cooper *et al.*, 1996). In SSVF CWs, an active sand layer with a depth of 1.0 m (effective grain size, $d_{10} = 0.25–1.2$ mm, coefficient of uniformity, $Cu < 3.5$) is recommended (Brix & Arias, 2005).

Treatment area and organic loading rates FWS CWs and SSHF CWs are normally sized in accordance with (Kadlec & Knight, 1996):

$$A = \left(\frac{0.0365Q}{k}\right)\ln\left(\frac{C_i - C^*}{C_e - C^*}\right) \qquad (1)$$

where A = required wetland area (ha), C_e = the outlet concentration (mg L^{-1}), C_i = inlet concentration (mg L^{-1}), C^* = background concentration (mg L^{-1}), k = first-order areal rate constant (m $year^{-1}$) and Q = hydraulic loading rate (m d^{-1}).

Depending on the water quality parameter used to size the CW, the constants in the model (C^* and k) may be different for FWS CWs and SSHF CWs (Kadlec & Knight, 1996). For example, if using BOD_5 to size a CW, $C^* = 3.5 + 0.053C_i$ for a FWS CW or a SSHF CW and k would be 34 and 180 m $year^{-1}$ for a FWS CW and a SSHF CW, respectively (Kadlec & Knight, 1996). In CW design, it is difficult to account for variables such as climate variation, pre-treatment control, and time to maturation. Therefore, design guidelines tend to be conservative. Organic and SS loading rates not exceeding 6 g BOD_5 m^{-2} d^{-1} and 5 g SS m^{-2} d^{-1}, respectively, are recommended for FWS CWs (US EPA, 1992). SSVF CWs may be operated in single-pass mode, intermittently loaded 8–12 times d^{-1}, or in recirculation mode, intermittently loaded 16–24 times d^{-1} (Brix & Arias, 2005). Winter & Goetz (2003) recommend a maximum organic loading rate of 20 g COD m^{-2} d^{-1} and a maximum SS influent concentration of 100 mg L^{-1} for SSVF CWs. Even when these loading conditions are satisfied, the performance of CWs may be variable.

Wetland vegetation Ireland has a cool temperate west maritime climate. In these climatic conditions, common reed (*Phragmites australis* (Cav.) Trin. ex Steud.) and common cattail (*Typha latifolia* L.) are mainly planted in CWs. As the amount of oxygen released by the emergent vegetation into the surrounding soil is small (Armstrong *et al.*, 1990), anaerobic conditions predominate. Harvesting of the emergent macrophytes has a pronounced effect on the growth and nutrient uptake rates. Although nutrient uptake and growth rates are higher in young vegetation stands (Greenway & Whoolley, 2001), other factors such as nutrient loading and hydraulic retention time (HRT) may significantly affect the uptake rates (Reddy *et al.*, 2001; Hardej & Ozimek, 2002). In cool temperate west maritime climates, shoot re-growth depends on the time of year at which harvesting takes place. Harvesting during June/July produces good shoot re-growth, whereas August/September harvesting tends not to produce significant re-growth.

Treatment efficiency SSHF CWs are ideal for cold climates because wastewater treatment occurs below the surface (Werker *et al.*, 2002). They are the most common CW system used in Europe (Vymazal, 2005). SSHF CWs have good organic, SS and faecal coliform removal rates but have poor NH_4-N removal rates (Neralla *et al.*, 2000; Weaver *et al.*, 2001; Steer *et al.*, 2005, Vymazal, 2005). In Texas, USA, Neralla *et al.* (2000) monitored 8 SSHF CWs comprising gravel media ranging in size from 0.95 to 1.6 cm and receiving domestic effluent from a septic tank. Under organic loading rates ranging from 2 to 5 g BOD_5 m^{-2} d^{-1}, average effluent BOD_5 and SS removals of 80% and 88%, respectively, were measured **(Table 1)**. An average NH_4-N removal of 39% was also measured and nitrification did not occur. These results were similar to Steer *et al.* (2005) who studied the performance of 8 SSHF CWs treating domestic effluent, comprising two

$25m^2$ SSHF CWs connected in series and preceded by a septic tank. Over a 5 year duration, average BOD_5 and SS removals of 69–98% and 77–83%, respectively, were measured and NH_4-N was reduced by approximately 70% (**Table 1**).

SSVF CWs are commonly used for domestic wastewater treatment. When the organic loading rate does not exceed a maximum allowable organic loading rate of 20 g COD m^{-2} d^{-1} (Winter & Goetz, 2003), they effectively remove organic matter, SS and nutrients (von Felde & Kunst, 1997). Luederitz *et al.* (2001) intermittently loaded a SSVF CW, comprising a 0.6 m active sand layer (sand/gravel, 0–4 mm) 800 m^2 in area and preceded by an anaerobic digester, at an organic loading rate of 35 g COD m^{-2} d^{-1} (21 g BOD_5 m^{-2} d^{-1}) and measured a COD removal of 94% and Tot-N removal of 61% **(Table 1)**. With a SSVF CW having the same active sand layer but preceded by two unaerated ponds and receiving an organic loading rate of 20 g COD m^{-2} d^{-1} (10 g BOD_5 m^{-2} d^{-1}), COD and Tot-N removals were 99.5% and 93.8%, respectively **(Table 1)**.

Recently, a modified version of the SSVF CW, the two-stage vertical flow constructed wetland (VFCW), has been gaining popularity in France, where there are currently around 400 VFCWs in operation (Molle *et al.*, 2006). The first stage of this system comprises three parallel vertical flow sand filters which are alternately intermittently dosed with raw wastewater at an organic loading rate of 300 g COD m^{-2} d^{-1}. In this first stage, COD and SS removal takes place. They contain a 30 cm-deep fine gravel layer (2–8 mm in size) which overlies a 10–20 cm-deep transition layer (5 mm in size) and a 10–20 cm-deep drainage layer (20–40 mm in size) (Molle *et al.*, 2005). The second stage comprises two identical vertical flow sand filters which contain a 30 cm-deep fine gravel layer (effective grain size, $d_{10} < 0.40$ mm) which overlies a 10–20 cm-deep transition layer (3–10 mm in size) and a 10–20 cm-deep drainage layer (20–40 mm in size) (Molle *et al.*, 2005). Nitrification mainly occurs in the second stage. Results from these systems have been good with COD and SS removals of 90 and 95%, respectively, being measured and nitrification at 85% (Molle *et al.*, 2005).

FWS CWs are also effective in organic matter, SS, and faecal coliform removal (Ran *et al.*, 2004) but, similar to SSHF CWs, have low N removals (Healy *et al.*, 2004; Ran *et al.*, 2004). Studies have reported settlement as the main N removal pathway (Toet *et al.*, 2005). In a 2-cell FWS CW, planted with duckweed and preceded by a preliminary storage tank and a primary sedimentation tank, Ran *et al.* (2004) measured average BOD_5 and SS removals of 71% and 80%, respectively, when the system was loaded at an organic loading rate of 16 g BOD_5 m^{-2} d^{-1}. Removal of N within the system seemed to be due mainly to sedimentation and plant uptake, as NH_4-N removals of 14% were measured **(Table 1)**.

When FWS CWs are in a marsh – retention pond – marsh formation, low flushing rates and little surface cover means that eutrophication may occur in the retention pond during warmer periods of the year (Healy & Cawley, 2002). In a 2-year study of a 3-cell FWS CW for tertiary treatment of municipal wastewaters in Williamstown, Ireland, Healy & Cawley (2002) measured average BOD_5 and SS removals of 49% and 90%, respectively **(Table 1)** but noted the occurrence of algal blooms in the retention pond during the summer months.

Intermittent sand filtration

ISF has been used for the treatment of domestic wastewater for over a hundred years. Sand filters may be operated either in single-pass or recirculation mode. In single-pass mode, following primary sedimentation, the wastewater is intermittently dosed onto a stratified sand filter (Gross & Mitchell, 1985). On a single pass through the system, organic carbon removal, ammonification and nitrification occurs. Factors affecting the retention of bacteria in porous media include straining, the grain size of the filter media, and the hydraulic loading rate (Stevik *et al.*, 2004). Removals of greater than 99.9% have been recorded for faecal coliforms (Vanlandingham & Gross, 1998). A study comparing single-pass sand filters (33.5 m^2), FWS CWs (53 m^2), and peat biofiltration systems (28 m^2) for the treatment of septic tank effluent (Puraflo^{TM}, Bord na Mona, Ireland) has shown that single-pass sand filters have the greatest organic and nutrient removal efficiency, although the difference in performance between the sand filtration and peat biofiltration systems is small (White, 1995). White (1995) measured organic carbon removals of 92% and nitrification of 91% for sand filters. Organic carbon removals of 87 and 82% were measured for the peat biofiltration and constructed wetland systems, respectively. No nitrification occurred in the constructed wetlands, and the percentage nitrification in the peat biofiltration systems was 90%.

Virus removal has also been estimated to occur in the first 30 cm of a stratified sand filter sand (Gross & Mitchell, 1985; Gross, 1990), although removal is dependent on the hydraulic loading rate and degree of saturation of the filter (Reneau *et al.*, 1989). In a series of columns containing medium concrete sand ($d_{10} = 0.32$ mm) and loaded with dechlorinated tap water containing MS2 bacteriophage at hydraulic loading rates of 51, 81, 12.2, and 16.3 L m^{-2} d^{-1}, Vanlandingham & Gross (1998) found average MS2 phage removal efficiencies of 99.6, 98.6, 99.9, and 97.2%, respectively.

In a normal single-pass filter operation, denitrification is limited by the absence of reducing conditions following nitrification and the lack of an available carbon source. This leads to poor Tot-N reduction and an effluent that is high in NO_3-N. In order that ISF offers a viable treatment alternative to conventional treatment methods, NO_3-N in the effluent needs to be denitrified. Recirculation of a major portion of the nitrified effluent from the sand filter through a denitrifying anoxic zone receiving the influent wastewater, located before the filter, offers a solution to this problem (USEPA, 1980). The recirculation ratio is defined by:

$$\alpha = \frac{Q_r}{Q} \quad (2)$$

where α is the recirculation ratio, Q_r is the return flow from the filter to the anoxic recirculation tank, and Q is the influent wastewater. Alternatively, external carbon sources can also be used in an anoxic reactor positioned after the nitrification reactor. Researchers have utilised methanol, ethanol, glucose, and acetate in denitrification (Lamb *et al.*, 1990; Carley & Mavinic, 1991). However, the widespread use of these chemicals has been hampered by the possibility of environmental hazards due to the toxicity of substances such as methanol (Lamb *et al.*, 1990). In attempts to reduce the hazards associated with such systems, researchers began to consider septic tank effluent as a source of carbon. However, the success of such a system depends largely on system design. Short contact times, a low carbon to nitrogen ratio (C:N) in the recirculation tank and high recirculation rates all result in poor denitrification rates in the system (Tebbutt, 1998).

To date, a number of variations on recirculating sand filters have been explored. At a hydraulic loading rate of 155–195 L m^{-2} d^{-1}, Lamb *et al.* (1990) found that denitrification was achieved when the sand filter effluent was mixed with three different carbon sources (methanol, ethanol and septic tank effluent) prior to entering a buried rock tank. With septic tank effluent as the carbon source, only 25% denitrification occurred, whereas methanol and ethanol produced a mean denitrification of 99%. This poor performance for the septic tank effluent was due to a C:NO_3-N ratio of 0.7:1 in the rock tank. Ethanol and methanol resulted in C:NO_3-N ratios of 2:1 and 4:1, respectively. Gold *et al.* (1992) encountered similar poor denitrification performance of a sand filter when the nitrified effluent was recirculated through a recirculation tank with an α ratio of 4:1 to 5:1. Tot-N removal increased from 8.4% (on a single pass through the sand filter) to 20% for recirculation. Again a low BOD_5:NO_3-N of approximately 1:1 in the recirculation tank limited denitrification. Optimal conditions for maximum denitrification occur at a COD: Tot-N ratio in the range of 4:1 to 5:1 for organic sludge (Henze *et al.*, 1997, Martinez, 1997; van Buuren *et al.*, 1999).

Biological clogging of filter media Biological clogging of the filter media is often problematic (Siegrist, 1987). Clogging of the upper layers of the sand filter increases the average water retention time in the filter and reduces the effective area available for water infiltration to a point where ponding occurs. Surface clogging may be due to a number of causes. Accumulation of microorganisms on surfaces as biofilms is believed to be the cause of surface sealing (Siegrist & Boyle, 1987; Vandevivere & Baveye, 1992; Schwager & Boller, 1997; Bouwer *et al.*, 2000). In this process, hydrated extracellular polymers (exopolymers) as well as cells accumulate on the upper layers of the sand media and give rise to a reduction in permeability (Schwager & Boller, 1997). Siegrist & Boyle (1987) found an accumulation of organic matter in the upper sand layer, and hypothesised that it may have undergone humification, and gradually filled the pore space, reducing the permeability. The type of filter media (Jowett & McMaster, 1995) and the deposition of organic and inorganic solids on the surface layer (Platzer & Mauch, 1997; Rodgers *et al.*, 2004) have also been considered to cause surface sealing.

Siegrist (1987) used gravimetric water content profiles to measure pore size reduction in an aggregate loaded with domestic septic tank effluent, greywater septic tank effluent, and tapwater. The most significant increases in water content near the infiltrative surface were attributed to the pore size reduction due to biomass build-up and, after 62 months of operation, the water contents in the upper 4 cm layer for treating tapwater and domestic septic tank effluent were 0.26 and 0.36, respectively. Conservative tracers such as sodium bromide (NaBr) can also be used to illustrate this effect (Schudel & Boller, 1990). Schwager & Boller (1997) used an F-curve (Levenspiel, 1999) in a 'clean' and 'used' filter to show the effect of biomass growth in the top filter layer on the prolongation of the retention time of a liquid.

Effect of dosing frequency on treatment performance

An increase in dosing frequency will have a beneficial effect on the treatment performance of a single-pass sand filter (Anderson *et al.*, 1985). In a study of 12 shallow sand filters (0.38 m deep), with four sets having the same d_{10} (0.29 mm) and uniformity coefficient (Cu = 4.5), Darby *et al.* (1996) found that for the same daily hydraulic loading rate, increasing the application frequency from 4 to 24 times per day resulted in a slight but statistically significant increase in the removal of turbidity, COD and organic-N (**Table 2**). In a field-scale experiment, Boller *et al.* (1993) showed that in a sand filter containing coarse sand ($d_{50} = 1.4$; $Cu = 4$) dosed daily with septic tank effluent, the filter performed better when loaded with 4 flushes of 10 L m^{-2} than when loaded with 1 flush of 40 L m^{-2} or 2 flushes of 20 L m^{-2}. Average sand filter effluent NH_4-N concentrations were 21.0, 17.2 and 3.8 mg NH_4-N L^{-1} at 1, 2, and 4 daily flushes, respectively. The results from a pilot-scale sand filter unit (Boller *et al.*, 1993), loaded at 6 times per day, are tabulated in **Table 2**.

Effect of media size and uniformity coefficient on treatment performance The uniformity coefficient (*Cu*) is defined as (Craig, 1997):

$$Cu = \frac{d_{60}}{d_{10}} \tag{3}$$

where d_{60} and d_{10} denote the largest possible sizes of the 60 and 10% fractions, respectively. The higher the uniformity coefficient, the larger the range of particle sizes in the sand. This may affect filter performance at higher hydraulic loading rates, as a well-graded sand means that small particles may fill interstices between large particles, leading to a reduction in the hydraulic conductivity, and possible blocking of the filter media.

Design specifications recommend that the sizing of the filter media should be in accordance with its use (USEPA, 1980; Ball & Denn, 1997; Loomis & Dow, 1999). For single-pass operation with a filter depth of 0.61–0.91 m, a d_{10} of 0.33 mm and $Cu < 3$ are recommended, whereas in recirculation mode, a d_{10} of 1.5–3.0 mm and *Cu* of 1.3–2.5 are recommended. Although increased nitrification has been attributed to a coarse grain size (Nielsen *et al.*, 1993), performance effects appear to be mostly related to hydraulic and organic loading rate and dosing frequency (Darby *et al.*, 1996). Nichols and Abboud (1995) found that complete organic carbon removal and good Tot-N removals (68–74%) were still attained when a chip stone ($d_{10} = 1.85$ mm; $Cu = 1.9$) and a pea gravel ($d_{10} = 2.05$ mm; $Cu = 2.7$) were used in a single-layer recirculating sand filter treating effluent from a restaurant.

Effect of organic and SS loading rates on performance The organic and SS loading rates have a significant effect on the clogging and performance of a filter. The US EPA (1980) recommend that, in single-pass sand filters, the organic loading rate should not exceed 22 g BOD_5 m^{-2} d^{-1} at a hydraulic loading rate of 40–80 L m^{-2} d^{-1}, whereas in recirculating sand filters the organic loading rate should not exceed 22 g BOD_5 m^{-2} d^{-1} at a hydraulic loading rate of 120–200 L m^{-2} d^{-1}. Results from single-pass and recirculating sand filters are given in **Tables 2** and **3**, respectively. A number of studies have investigated the filter performance under varying loading rates in an attempt to quantify the maximum organic and SS loading rates that can be safely applied to a filter (Darby *et al.*, 1996; Nichols *et al.*, 1997). Nichols *et al.* (1997) found that, when the COD and SS loading rates on a 1 m-deep, 3-layer stratified sand filter were increased to 15 and 1.0 g m^{-2}d^{-1}, respectively, reduced rates of nitrification occurred.

Effert *et al.* (1985) applied domestic effluent onto a sand filter 76 cm deep ($d_{10} = 0.4$ mm; $Cu = 2.5$) at an organic loading rate of 20 g BOD_5 m^{-2} d^{-1} and found that almost complete organic removal occurred, but in the absence of denitrifying conditions, Tot-N was reduced by only 1–11%, with the effluent Tot-N mainly present as NO_3-N. In an analysis of 50 sand filters, with an effective size (d_{10}) of 0.2–0.3 mm, treating domestic effluent, Nielsen *et al.* (1993) showed that at an average organic loading rate of approximately 10 g BOD_5 m^{-2} d^{-1}, 90–95% of the BOD_5 and 30–45% of the Tot-N was removed.

The organic and SS loading rates can have a significant effect on the clogging and performance of a filter. A number of studies have investigated the filter performance under varying loading rates in an attempt to quantify the maximum organic and SS loading rate which can safely be applied to a filter (Nichols & Abboud, 1995; Darby *et al.*, 1996).

Alternative single-pass filter designs

A number of alternative filter designs have been proposed. Latvala (1993) proposed the use of a multilayer intermittent sand filter, wherein wastewater is loaded through three gravel layers at incremental depths in the layered filter column. Varying the organic loading rate between 83 and 166 g COD m^{-2} d^{-1}, only 54% of the organic matter was removed in the filter. Jowett & McMaster (1995) experimented with a set-up similar to that used later by Leverenz *et al.* (2000). They used a single-pass unsaturated biofilter, composed of foam, to treat synthetic domestic effluent at a hydraulic loading rate of 800 L m^{-2} d^{-1}. They found that the system only performed well under conditions of forced ventilation, giving complete nitrification and over 98% organic matter removal. Using natural air convection, nitrification was incomplete (effluent NH_4-N concentration was 10.2 mg L^{-1}), and organic matter removal was at 93%. The multi-soil-layering (MSL) method has also been used to purify domestic effluents

(Wakatsuki *et al.*, 1993; Luanmanee *et al.*, 2001). It consists of 1.2 m-deep soil-mixture blocks (containing metal iron and pelletized jute; the jute is used as a carbon-source for denitrification) in a brick-like pattern with zeolite interlayers. They are capable of operating under an organic and hydraulic loading rate of 4–15 g BOD_5 m^{-2} d^{-1} and 100–850 L m^{-2} d^{-1}, respectively, without significant clogging. Over a 1-year study period, the BOD_5 and Tot-N was reduced by 80–95% and 80–91%, respectively (Wakatsuki *et al.*, 1993). The Tot-N reduction may be due to NH_4-N absorption onto the zeolite. The MSL system is, however, a mechanical aeration system. It is highly sensitive to aeration (Luanmanee *et al.*, 2001) and excessive dosing can lead to reduced denitrification rates.

In a study using non-woven textile fabrics (NWTF) as filter media, Leverenz *et al.* (2000) used three filter configurations (hanging sheets of textile fabric, single layer textile fabric chips (approximately 30 × 20 mm in size), and 3 independent layers of textile fabric chips (size not quoted)) to treat domestic-strength wastewater over a period of 7 months. Due to the random stacking arrangement of the textile fabrics, the filter media had a high porosity and hydraulic conductivity. The filters were operated in recirculation mode with recirculation ratios of 9:1 and 3:1 for two hydraulic loading rates of 410 and 1220 L m^{-2} d^{-1}, respectively, on the plan surface area of the filter. Using mechanical aeration, the filters produced an effluent that was low in nutrients and organic matter under maximum COD and SS loading rates of 141 and 76 g m^{-2} d^{-1}, respectively.

SSVF CWs and ISF

SSVF CWs remove organic matter, SS and nitrify N (Brix *et al.*, 2002; Weedon, 2003) but, similar to ISF, have poor long-term P removal rates (Brix & Arias, 2005). Both systems are limited by the maximum organic loading rate that may be applied to their surfaces. Depending on the strength of the influent wastewater, a maximum organic loading rate of approximately 24 g COD m^{-2} d^{-1} may be applied in ISF (Rodgers *et al.*, 2005), whereas a maximum organic loading rate of 20 g COD m^{-2} d^{-1} is recommended for SSVF CWs (Winter & Goetz, 2003). SSVF CWs are differentiated from ISF by their surface covering of emergent vegetation which affects the infiltration of wastewater into the filter media (Molle *et al.*, 2006).

Conclusions

This article reviewed the currently used practices of constructed wetlands, single-pass and recirculating sand filters for the treatment of dairy parlour wastewaters. To date, ISF of high strength wastewaters is an emerging technology; therefore, there is not strong research antecedence in their use in an agricultural setting. While FWS CWs, SSHF and SSVF CWs are regularly used for the treatment of agricultural wastewaters, they appear to be limited by the organic loading rate that may be applied to them. In comparison, ISF, though possibly requiring greater monitoring and maintenance can accept a higher organic loading rate and has a much smaller footprint.

Acknowledgements Author acknowledge to department of chemical engineering, ITGGV, Bilaspur for funding and facilities.

References

Anderson, D.L., Siegrist, R.L., Otis, R.J. (1985) Technology assessment of intermittent sand filters. Report No. PB85-232585. Municipal Facilities Division, Office of Municipal Pollution Control, Washington, D.C. USA.

Armstrong, W., Armstrong, J. and Beckett, P.M. (1990) Measurement and modelling of oxygen release from roots of *Phragmites australis*. In: P.F. Cooper, B.C. Findlater (eds), Constructed Wetlands in Water Pollution and Control, Oxford, 41–51. UK.

Bachand, P.A.M., Horne, A.J. (2000) Denitrification in constructed wetland free-water surface wetlands:II. Effects of vegetation and temperature. *Ecol. Eng.* **14**, 17–32.

Ball, J.L., Denn, G.D. (1997) Design of recirculating sand filters using a standardized methodology. In: M.S. Bedinger, A.I. Johnson, and J.S. Fleming (eds). Site characterisation and design of on-site septic systems, ASTM STP 898. American Society for Testing and Materials. West Conshohocken, PA, USA, 191–206.

Boller, M., Schwager, A., Eugster, J., Mottier, V. (1993) Dynamic behaviour of intermittent buried filters. *Wat. Sci. and Tech.* **28**(10), 99–107.

Bouwer, E.J., Rijnaarts, H.H.M., Cunningham, A.B., Gerlach, R. (2000) Biofilms in porous media. In: J.D. Bryers (ed.), Biofilms II: Process analysis and applications. Wiley, NY, USA, 123–158.

Brix, H., Arias, C.A. (2005) The use of vertical flow constructed wetlands for on-site treatment of domestic wastewater: new Danish guidelines. *Ecol. Eng.* **25**, 491–500.

Brix, H., Arias, C.A., Johansen, N.H. (2002) BOD and nitrogen removal from municipal wastewater in an experimental two-stage vertical flow constructed wetland system with recycling. In: Proceedings of the eight international conference on wetland systems for water pollution control. Arusha, Tanzania, 16–19 September, 400–410.

Carley, B.N., Mavinic, D.S. (1991) The effects of external carbon loading on nitrification and denitrification of a high ammonia landfill leachate. *J. Wat. Poll. Cont. Fed.* **63**, 51–59.

Carton, O.T. (2001) Environmental pressures and national environmental legisation with respect to nutrient management. In: P De Clercq *et al.* (ed.), Nutrient Management Legislation in European Countries. Department of Soil Management and Soil Care, Faculty of Agricultural and Applied Biological Sciences. Wageningen, The Netherlands, 89–204.

Cooper, P., Job, G.D., Green, M.B., Shutes, R.B.E. (1996) Reed beds and constructed wetlands for wastewater treatment. WRc, Swindon, UK, 184 pp.

Craig, R.F. (1997) Soil Mechanics. 7th edition. E & FN Spon, London. E&FN Spon, London., UK, 447 pp.

Darby, J., Tchobanoglous, G., Nor, M.A. (1996) Shallow intermittent sand filtration: performance evaluation. *The Small Flows J.* **2**, 3–14.

EEC. (1991) Council Directive concerning the protection of waters against pollution caused by nitrates from agricultural sources. Council of European Communities, 91/676/01-07.

Effert, D., Morand, J., Cashell, M. (1985) Field performance of three onsite effluent polishing units. Proceedings of the fourth national symposium on individual and small community sewage systems. New Orleans, LA, USA. December 10-11, 1984. *ASAE Publ.* 07-85, 1–11.

EPA (2000) Wastewater treatment manuals: Treatment systems for single houses. Environmental Protection Agency, Wexford, Ireland. 58 pp + appendices.

Faulkner, S.P., Richardson, C.J. (1989) Physical and chemical characteristics of freshwater wetland soils. In: D.A. Hammer (ed.), Constructed wetlands for wastewater treatment. Lewis Publishers, Chelsea, MI, pp. 71–72.

Geary, P.M., Moore, J.A. (1999) Suitability of a treatment wetland for dairy wastewaters. *Wat. Sci. and Tech.* **40**(3), 179–185.

Gold, A.J., B.E. Lamb, G.W. Loomis, J.R. Boyd, V.J. Cabelli, and C.G. McKiel. (1992) Wastewater renovation in buried and recirculating sand filters. *J. Env. Qual.* **21**, 720–725.

Greenway, M., Woolley, A. (2001) Changes in plant biomass and nutrient removal over 3 years in a constructed wetland in Cairns, Australia. *Wat. Sci. and Tech.* **44**(11-12), 303–310.

Gross, M. (1990) Virus removal by sand filtration of septic tank effluent. *J. Env. Eng.* **116**, 711–720.

Gross, M., Mitchell, D. (1985) Biological virus removal from household septic tank effluent. Proc. fourth national symposium on individual and small community sewage systems. New Orleans, LA, USA. December 10-11, 1984. *ASAE Publ.* 07-85, 295–304.

Hardej, M., Ozimek, T. (2002) The effect of sewage sludge flooding on growth and morphometric parameters of Phragmites australis (Cav.) Trin. Ex Steudel. *Ecol. Eng.* **18**, 343–350.

Healy, M.G., Cawley, A.M. (2002) The nutrient processing capacity of a constructed wetland in western Ireland. *J. Env. Qual.* **31**, 1739–1747.

Healy, M.G., Rodgers, M., Mulqueen, J. (2004) Recirculating sand filters for treatment of synthetic dairy parlor washings. *J. Env. Qual.* **33**, 713–718.

Henze, M., Harremoes, P., Jansen, J.L.C., Arvin, E. (1997) Wastewater treatment: biological and chemical processes. 2nd edition. Springer Publication, Berlin, Germany.

Jowett, E.C., McMaster, M.L. (1995) On-site wastewater treatment using unsaturated adsorbent biofilters. *J. Env. Qual.* 24, 86–95.

Kadlec, R.H. (1997) An autobiotic wetland phosphorus model. *Ecol. Eng.* **8**, 145–172.

Kadlec, R.H., Knight, R.L. (1996) Treatment wetlands. CRC Press, Baco Raton, FL, USA. 893 pp.

Karpiscak, M.M., Freitas, R.J., Gerba, C.P., Sanchez, L.R., Shamir, E. (1999) Management of dairy waste in the Sonoran Desert using constructed wetland technology. *Wat. Sci. and Tech.* **40**(3), 57–65.

Knight, R.L., Payne Jr., V.W.E., Borer, R.E.,Clarke Jr., R.A., Pries, J.H. (2000) Constructed wetlands for livestock management. *Ecol. Eng.* **15**, 41–55.

Lamb, B.E., Gold, A.J., Loomis, G.W., McKiel, C.G. (1990) Nitrogen removal for on-site sewage disposal: a recirculating sand filter / rock tank system. *Trans. ASAE* **33**, 525–531.

Latvala, A. (1993) Multilayer intermittent sand filter. *Wat. Sci. and Tech.* **28**(3), 125–132.

Levenspiel, O. (1999) Chemical reaction engineering. 3rd edition. John Wiley & sons. New York, USA. 668 pp.

Leverenz, H., Darby, J., Tchobanoglous, G. (2000) Evaluation of textile filters for the treatment of septic tank effluent. Report No. 2000-1. Centre for Environmental and Water Resources Engineering, University of California, Davis. CA, USA.

Liu, Q., Mancl, K., Tuovinen, O.H. (2000) High fat wastewater remediation using layered sand filter biofilm systems, In: Proceedings of the international symposium on animal, agricultural and food processing wastes, ASAE, St. Joseph, Michigan, 242–248.

Liu, Q., Mancl, K., Tuovinen, O.H. (2003) Biomass accumulation and carbon utilization in layered sand filter biofilm systems receiving milk fat and detergent mixtures, Biores. Tech. **89**, 275–279.

Liu, Q., Mancl, K.M., Tuovinen, O.H. (1998) Effect of inoculation on the biodegradation of butterfat-detergent mixtures in fixed-film sand columns, *Biores. Tech.* **64**, 27–32.

Loomis, G., Dow, D. (1999) Guidelines for the design and use of sand filters in critical resource areas. Rhode Island Department of Environmental Management, NY, USA.

Luanmanee, S., Attanandana, T., Masunaga, T., Wakatsuki T. (2001) The efficiency of a multi-soil-layering system on domestic wastewater treatment during the ninth and tenth years of operation. *Ecol. Eng.* **18**, 185–199.

Luederitz, V., Eckert, E., Lange-Weber, M., Lange, A., Gersberg, R.M. (2001) Nutrient removal efficiency and resource economics of vertical flow and horizontal flow constructed wetlands. *Ecol. Eng.* **18**, 157–171.

Maehlum, T., Jenssen, P.D., Warner, W.S. (1995) Cold-climate constructed wetlands. *Wat. Sci. and Tech.* **32**(3), 95–101.

Martinez, J. (1997) Solepur: a soil treatment process for pig slurry with subsequent denitrification of drainage water. *J. Eng. Res.* **66**, 51–62.

Molle, P., Liénard, A., Boutin, C., Merlin, G., Iwema, A. (2005) How to treat raw sewage with constructed wetlands: an overview of the French systems. *Wat. Sci. and Tech.* **35**(6), 11–21.

Molle, P., Liénard, A., Grasmick, A., Iwema, A. (2006) Effect of reeds and feeding operations on hydraulic behaviour of vertical flow constructed wetlands under hydraulic overloads. *Wat. Res.* **40**, 606–612.

Molle, P., Liénard, A., Grasmick, A., Iwema, A. (2006) Effect of reeds and feeding operations on hydraulic behaviour of vertical flow constructed wetlands under hydraulic overloads. *Wat. Res.* **40**, 606–612.

Neralla, S., Weaver, R.W., Lesikar, B.J., Persyn, R.A. (2000) Improvement of domestic wastewater quality by subsurface flow constructed wetlands. *Biores. Tech.* **75**, 19–25.

Nichols, D.J., Wolf, D.C., Gross, M.A., Rutledge, E.M. (1997) Renovation of septic effluent in a stratified filter. In: M.S. Bedinger, J.S. Fleming, and A.I. Johnson (eds), Site characterisation and design of on-site septic systems. ASTM STP 1324. American Society for Testing and Materials. West Conshohocken, PA, USA, 235–247.

Nichols, J.R., Abboud, N.M. (1995) Recirculating sand filters in Connecticut. *Fluid / Particle Separation J.* **8**, 175–189.

Nielsen, J., Lynggaard-Jensen, A., Hasling, A. (1993) Purification efficiency of Danish biological sand filter systems. *Wat. Sci. and Tech.* **28**(10), 89-97.

Patrick, W.H., Khald, R.A. (1974) Phosphate release and sorption by soils and sediments: effect of aerobic and anaerobic conditions. *Science* **186**, 53–55.

Platzer, C., Mauch, K. (1997) Soil clogging in vertical flow reed beds – mechanisms, parameters, consequences and… solutions? *Wat. Sci. and Tech.* **35**(5), 175–181.

Ran, N., Agami, M., Oron, G. (2004) A pilot study of constructed wetlands using duckweed (*Lemma gibba* L.) for treatment of domestic primary effluent in Israel. *Wat. Res.* **38**, 2241–2248.

Reddy, G.B., Hunt, P.G., Phillips, R., Stone, K., Grubbs, A. (2001) Treatment of swine wastewater in marsh-pond-marsh constructed wetlands. 2001. *Wat. Sci. and Tech.* **44**(11–12), 545–550.

Reneau, R.B., Hagedorn, C., Degen, M.J. (1989) Fate and transport of biological and inorganic contaminants from on-site disposal of domestic wastewater. *J. of Env. Qual.* **18**, 135–144.

Richards, K., Ryan, M., Coxon, C. (1998) Leaching of N compounds from swards used for dairying that are N-based and irrigated with dirty water/slurry. End of project report. ARMIS 3635. Teagasc. Johnstown Castle Research Centre, Wexford, Ireland.

Richardson, C.J., and C.B. Craft. (1993) Effective phosphorus retention in wetlands: Fact or fiction. In: G.A. Morshiri (ed.), Constructed wetlands for water quality improvement. Lewis Publishers, London, 271–282.

Rodgers, M., Mulqueen, J., Healy, M.G. (2004) Surface clogging in an intermittent stratified sand filter. *Soil Sci. Soc. Am. J.* **68**, 1827–1832.

Rousseau, D.P.L., Vanrolleghem, P.A., De Pauw, N. (2004) Constructed wetlands in Flanders: a performance analysis. *Ecol. Eng.* **23**, 151–163.

Schwager, A., Boller, M. (1997) Transport phenomena in intermittent filters. *Wat. Sci. and Tech.* **35**(6), 13–20.

Shatwell, T., Cordery, I. (1999) Nutrient storage in urban wetlands. In: B. Ellis (ed.) Impacts of urban growth on surface water and groundwater quality. *IAHS Publ.* 259, Wallingford, UK, 339–347.

Siegrist, R.L. (1987) Soil clogging during subsurface wastewater infiltration as affected by effluent composition and loading rate. *J. Env. Qual.* **16**, 181–187.

Siegrist, R.L., Boyle, W.C. (1987) Wastewater-induced soil clogging development. *J. Env. Eng.* ASCE **113**, 550–566.

Steer, D.N., Fraser, L.H., Seibert, B.A. (2005) Cell-to-cell pollution reduction effectiveness of subsurface domestic treatment wetlands. *Biores. Tech.* **96**, 969–976.

Stevik, T.K., Aa, K., Ausland, G., Hanssen, J.F. (2004) Retention and removal of pathogenic bacteria in wastewater percolating through porous media: a review. *Wat. Res.* **38**, 1355–1367.

Szogi, A.A., Vanotti, M.B., Hunt, P.G. (2006) Dewatering of phosphorus extracted from liquid swine waste. *Biores. Tech.* **97**, 183–190.

Tebbutt, T.H.Y. (1998) Principles of water quality control. 5th edition. Butterworth-Heinemann, Oxford, UK.

Toet, S., Van Logtestijn, R.S.P., Schreijer, M., Kampf, R., Verhoeven, J.T.A. (2005) The functioning of a wetland system used for polishing effluent from a sewage treatment plant. *Ecol. Eng.* **25**, 101–124

Toner, P., Bowman, J., Clabby, K., Lucey, J., McGarrigle, M., Concannon, C., Clenaghan, C., Cunningham, P., Delaney, J., O'Boyle, S., MacGarthaigh, M., Craig, M., Quinn, R. (2005) Water quality in Ireland. Environemental Protection Agency, Co. Wexford, Ireland.

U.S. Environmental Protection Agency (1980) Design manual: onsite wastewater treatment and disposal systems. EPA Report no. 625/1-80-012. Cincinnati, OH, USA.

Van Buuren, J.C.L., Abusam, A., Zeeman, G., Lettinga, G. (1999) Primary effluent filtration in small-scale installations. *Wat. Sci. and Tech.* **39**(5), 195–202.

Vandevivere, P., Baveye, P. (1992) Effect of bacterial extracellular polymers on the saturated hydraulic conductivity of sand columns. *Appl. Environ. Microbiol.*, May, 1690–1698.

Vanlandingham, D.S., Gross, M.A. (1998) Contaminant distribution in intermittent sand filters. *ASAE Publ.* 03/98, 380-387.

Vanlandingham, D.S., Gross, M.A. (1998) Contaminant distribution in intermittent sand filters. *ASAE Publ.* 03/98, 380–387.

Vanotti, M.B., Rice, J.M., Ellison, A.Q., Hunt, P.G., Humenik, F.J., Baird, C.L. (2005) Solid-liquid separation of swine manure with polymer treatment and sand filtration. *Am. Soc. Agric. Eng.* **48**, 1567–1574.

Von Felde, K., Kunst, S. (1997) N- and COD-removal in vertical-flow systems. *Wat. Sci. and Tech.* **35**(5), 79–85.

Vymazal, J. (2002) The use of sub-surface constructed wetlands for wastewater treatment in the Czech Republic: 10 years experience. *Ecol. Eng.* **18**, 633–646.

Vymazal, J. (2005) Horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment. *Ecol. Eng.* **25**, 478–490.

Wakatsuki, T., Esumi, H., Omura, S. (1993) High performance and N & P-removable on-site domestic waste water treatment system by multi-soil-layering method. *Wat. Sci. and Tech.* **27**(1), 31–40.

Weaver, R.W., Lane, J.J., Johns, M.J., Lesikar, B.J. (2001) Uptake of 15N by macrophytes in subsurface-flow wetlands treating domestic wastewater. *Env. Tech.* **22**, 837–843.

Weedon, C.M. (2003) Compact vertical flow constructed wetland systems – first two years' performance. *Wat. Sci. and Tech.* **48**(5), 15–23.

Werker, A.G., Dougherty, J.M., McHenry, J.L., Van Loon, W.A. (2002) Treatment variability for wetland wastewater treatment design in cold climates. *Ecol. Eng.* **19**, 1–11.

White, J.S., Bayley, S.E., Curtis, P.J. (2000) Sediment storage of phosphorus in a northern prairie wetland receiving municipal and agro-industrial wastewater. *Ecol. Eng.* **14**, 127–138.

White, K.D. (1995) Performance and economic feasibility of alternative on-site wastewater treatment and disposal options: peat biofilters, constructed wetlands, and intermittent sand filters. In: Proceedings of the 68th Annual Conference and Exposition. Water Environment Federation, Miami, FL, USA. 129–138.

Winter, K.J., Goetz, D. (2003) The impact of sewage composition on the soil clogging phenomena of vertical flow constructed wetlands. *Wat. Sci. and Tech.* **48**(5), 9–14.