

REACTIVE FILTER SYSTEMS FOR SMALL SCALE WASTEWATER TREATMENT

A literature review

by ANNELIE HEDSTRÖM, Department of Civil and Environmental Engineering
Luleå University of Technology, 971 87 Luleå
e-mail: Annelie.Hedstrom@lulemail.net



Abstract

The objective of this study was to outline via a literature review reactive filter systems for small scale wastewater treatment. Phosphorus and ammonium sorption were considered. Different reactive filter materials have been studied in a laboratory, though few in full-scale. The lightweight clay aggregate product Filtralite P and Nordkalk Filtra P are the materials most used in full-scale applications and sorb phosphorus efficiently. Blast furnace slag and Polonite are other promising phosphorus sorbents, but require full-scale studies before they can be recommended. A reactive filter system needs at least a sludge separation unit, a pre-treatment step and a reactive filter. The pre-treatment step contributes to the BOD and nitrogen removal and decreases the clogging risk of the reactive filter unit. Locating the reactive filter material in a separate filter unit facilitates the replacement of exhausted material and the recovery of sorbed nutrients. Ammonium adsorbs efficiently to zeolites, but larger amounts of filter material are needed for ammonium adsorption compared to corresponding systems for phosphorus sorption due to higher wastewater concentrations. Further research is needed regarding the longevity of the sorbents, influence of resting periods, leakage of sulphuric compounds and heavy metals, desorption, risks of using sorbents as fertilisers and system analyses.

Key words – phosphorus, ammonium, reactive filter system, pre-treatment, filter media, blast furnace slag, LWA, polonite, sorption, adsorption

Sammanfattning

Syftet med detta arbete var att göra en litteraturstudie om reaktiva filtersystem för småskalig avloppsvattenbehandling. Både fosfor och ammonium beaktades. Olika reaktiva filtermaterial har studerats i laboratorier men endast ett fåtal i full skala. LWA produkten Filtralite P och Nordkalk Filtra P är de material som studerats mest i fullskaletillämpningar och sorberar fosfor effektivt. Masugnsslagg och Polonit är andra lovande sorbenter, men fullskalförsök krävs innan de kan rekommenderas. Ett reaktivt filtersystem bör åtminstone bestå av en slamavskiljare, ett förbehandlingssteg och ett reaktivt filter. Förbehandlingssteget bidrar till BOD- och kvävereduktion samt minskar risken för igensättning av det reaktiva filtret. En placering det reaktiva filtermaterialet i separata enheter underlättar byte och användning av sorberade näringsämnen. Ammonium adsorberas effektivt till zeoliter men större mängder filtermaterial krävs för ammoniumadsorption i jämförelse med motsvarande system för fosforsorption på grund av högre koncentrationer i avloppsvattnet. Fortsatta studier krävs angående sorbenternas livslängd, inverkan av viloperioder på sorptionskapaciteten, utlakning av svavelhaltiga föreningar och tungmetaller, desorption, risker med att använda mättade sorbenter som gödselmedel samt systemanalyser.

Introduction

The interest for reactive filter systems for small scale wastewater treatment has grown in recent years. Reactive filter materials are available for both phosphorus and ammonium sorption, even though phosphorus sorbents have attracted the most attention.

One reason for the growing interest in reactive filter materials is the insufficient phosphorus treatment efficiency of conventional small wastewater treatment systems. In Europe, sewage treatment from single houses and small rural communities is becoming important for improving the environmental quality in streams and lakes (Brix et al., 2001). Even though only 15 % of the

Swedish population is connected to on-site wastewater treatment systems (SCB, 2004), the total discharge of phosphorus from these systems exceeds the total discharge from all municipal treatment plants in Sweden (SEPA, 2003). Furthermore, a majority of the existing small wastewater treatment systems in Sweden will not fulfil the new criteria regarding nutrient removal and recovery (Ejhed et al., 2004; Malmén et al., 2004; SEPA, 2006).

Objectives, Scope and Method

The objective of this study was to give an overview of reactive filter systems for small scale wastewater treatment, and phosphorus as well as ammonium sorption were considered.

The study was performed as a literature review, using international scientific databases and the Internet for the literature search. Telephone interviews were also done.

Reactive filter Systems

System Description

A small wastewater treatment system with a reactive filter unit can be built and installed without changing any sanitary installations within the houses. Units that can be included in a reactive filter system are a sludge separation unit, such as a septic tank, a pre-treatment step, and finally, a reactive filter unit, see Figure 1. The largest particles are separated from the wastewater in the septic tank, but further wastewater treatment is needed prior to the reactive filter unit to prevent clogging of the reactive filter material. Therefore, a pre-treatment step should be located before the reactive filter to further separate suspended solids and organic matter from the wastewater. Depending on the topography, a pump preceding the pre-treatment step may be needed to facilitate wastewater distribution into the reactive filter. In the reactive filter, phosphorus or ammonium is sorbed

to the materials by physical adsorption, chemisorption or precipitation (Montgomery, 1985; McBride, 1994).

The incorporation of reactive filter materials in sand filter beds or infiltration systems to improve the phosphorus removal has also been investigated (Nilsson, 1990; Vilpas et al., 2005b). However, with this approach, the exchange of exhausted material is complicated and the recovery of sorbed nutrients is obstructed. Therefore, these systems are not discussed further in this study.

Pre-treatment step

Function

Different designs of the pre-treatment step have been suggested and investigated, though their overall purpose has been the same, i.e. to reduce suspended solids and organic compounds in wastewater (Jenssen et al., 2005) and to prevent clogging and competition about the sorption sites of the reactive filter material. The treatment mechanism for the removal of organic compounds is mainly biological degradation. Depending on the design, nitrification of ammonium can also be considerable in the pre-treatment step. However, if the aim of the reactive filter is ammonium adsorption, it is important that the wastewater ammonium not be converted to nitrite and nitrate.

Full-scale pre-treatment steps

Different types of full-scale pre-treatment steps have been investigated. Maehlum and Stålnacke (1999) and Heistad et al. (2004) studied water unsaturated gravel or LECA beds through which the wastewater percolates vertically. The wastewater was distributed by pipes (Maehlum and Stålnacke, 1999) or nozzles (Heistad et al., 2004). The nozzles aerated the wastewater and distributed it more evenly than the pipes. Arias et al. (2003a, 2003b) studied a water unsaturated vertical flow bed planted with reeds (*Phragmites australis*). A small vertical water unsaturated gravel bed combined with a horizontal water saturated gravel bed (4x8 m) planted

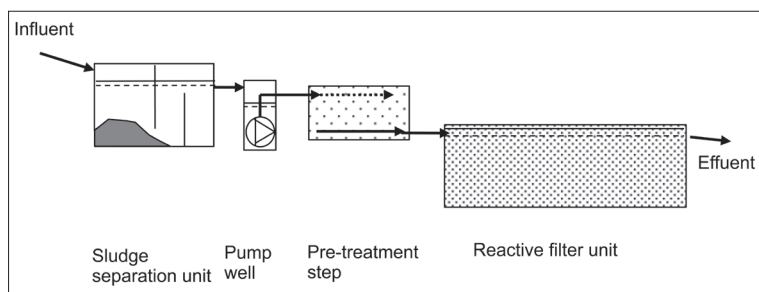


Figure 1. Outline of wastewater treatment system with a reactive filter.

Figure 2. *Pre-treatment step – gravel bed planted with willows, Luleå (Rastas, 2006).*



with willows, began operating during the spring 2005 in Luleå (Rastas, 2006); see Figure 2. Using a conventional sand filter bed as a pre-treatment step before the reactive filter unit has also been investigated (Vilpas et al., 2005b).

Reactive filter materials

Investigated reactive filter materials for phosphorus sorption

Reactive filter materials for phosphorus sorption have been greatly studied in recent years. The investigated materials can be divided into three groups, namely natural substrates, industrial by-products and industry produced products.

The investigated natural substrates are, e.g., limestone (Drizo et al., 1999; Brix et al., 2001; Arias and Brix, 2005a; Shilton et al., 2005), wollastonite (Brooks et al., 2000; Hedström, 2006), opoka (Johansson, 1999b; Johansson and Gustavsson, 2000), shell and shell sand (Roseth, 2000; Arias and Brix, 2005a, Søvik and Kløve, 2005), and biotite (Vilpas et al., 2005b).

Blast furnace slag is the most investigated industrial by-product for phosphorus sorption (Mann and Bavor, 1993; Sakadevan and Bavor, 1998; Johansson, 1999a; Johansson, 1999b; Johansson and Gustavsson, 2000; Grüneberg and Kern, 2001; Cameron et al., 2003; Rastas, 2003; Hylander et al., 2006); see Figure 3. It is produced in steel plants derived from slag forming minerals, mainly limestone, during iron production in a blast furnace (Tossavainen, 2005). Electric arc furnace steel slag (Drizo et al., 2002), melter slag (Shilton et al., 2006) and fly ash (Mann and Bavor, 1993; Drizo et al., 1999; Agyei et al., 2002) are other industrial by-products that have been examined.

Different kinds of lightweight clay aggregates (LWA, LECA) have been investigated as filter materials (Johansson, 1997; Zhu et al., 1997; Drizo et al., 1999; Brix

et al., 2001; Zhu et al., 2003). Filtralite P (Heistad et al., 2004; Adam et al., 2005; Adam et al., 2006) is an LWA product especially produced and investigated for phosphorus sorption in wastewater treatment systems. Polonite produced from opoka is another material developed for sorption applications (Eveborn, 2003; Renman et al., 2004; Hylander et al., 2006). Furthermore, granules consisting of lime, iron compounds and gypsum (Nordkalk Filtra P) were recently developed in Finland as phosphorus sorbent (Vilpas et al., 2005b).

Investigated reactive filter materials for ammonium adsorption

Different kinds of natural zeolites are the most studied adsorbents regarding ammonium adsorption in wastewater treatment applications, of which clinoptilolite is believed to be the most investigated due to numerous studies (Koon and Kaufmann, 1975; Jørgensen et al., 1976; Hlavay et al., 1982; Beler-Baykal and Guven, 1997; Nguyen, 1997; Demir et al., 2002). Wollastonite (Lind et al., 2000; Granrot, 2005; Hedström, 2006) was also investigated for ammonium adsorption.



Figure 3. *Blast furnace slag (3–6 mm).*

Reactive filter systems investigated in full-scale

Most reactive filter materials have only been investigated by laboratory experiments. However, full-scale experiments must be conducted before any materials can be recommended. LWA products, such as Filtralite P, a few slag materials and Nordkalk Filtra P are reactive filter materials that have been investigated in full-scale. Numerous full-scale filter bed systems have been built in Norway during the last decade, the majority of which use LWA in the filter bed section (Jenssen et al., 2005). More than 200 of these systems use Filtralite P (Rystad, personal communication, 2006). About 70–80 compact reactive filter systems using Nordkalk Filtra P have been built in Finland during the last 2–3 years (Carla, personal communication, 2006). Reactive filter systems with blast furnace slag for small scale wastewater treatment have hardly been investigated in full-scale. However, one such reactive filter system was constructed in Luleå in 2005 (Rastas, 2006). In Turkey, a reactive filter bed using blast furnace slag and planted with *Phragmites australis* was built in 2001 to treat domestic wastewater (3 m³/d) (Korkusuz et al., 2005). A larger reactive filter system to treat urine-separated wastewater was built in 2003 at a highway rest stop with toilet facilities in Ångersjön, Hudiksvall. In one of the treatment lines, a filter bed with blast furnace slag for phosphorus sorption was placed after a limestone filter (Stråe, 2005). In Canada, blast furnace slag was investigated in an experimental plant with reactive filter beds, designed for about 100 inhabitants, to treat lagoon and wetland effluents (Cameron et al., 2003). In New Zealand, a pond system for a population of about 6,000 was upgraded in 1993 with steel slag filters to increase the phosphorus removal (Shilton et al., 2006). The components of small scale reactive filter systems investigated in full-scale are compiled in Table 1.

A small scale multi-soil layering system to treat domestic wastewater from one household was investigated in Japan. Clinoptilolite was included as a structure material in the system (Luanmanee et al., 2001).

Design of reactive filter units

The design, operation and treatment performance of reactive filters are dependent on the design and function of the pre-treatment step. For example, the more efficient the pre-treatment, the finer the reactive filter material with higher sorption capacity can be used.

Design of large filters for phosphorus sorption

Different designs have been suggested for reactive filters. Norwegian reactive filter beds are probably the systems most studied. Characterised by large units with about 40 m³ of reactive filter material (Filtralite P) per household, they are expected to last 10–15 years (Gaut and Maehlum, 2001; Jenssen et al., 2005). The depth of the filter bed is about 1 m; the width at least 4.5 m. The filter bed is water saturated and operated with a horizontal flow. Furthermore, the bed can be located under a lawn in the garden or vegetated with common reed (Jenssen et al., 2005). In recent years, somewhat smaller filter beds using about 25 m³ Filtralite P have been constructed (Rystad, personal communication, 2006).

Design of small filters for phosphorus sorption

Arias et al. (2003a) pointed out that reactive filter systems should be designed with separate filter units to facilitate the exchange of exhausted material. Furthermore, a more compact system decreases the volume of material needed, and hence the construction costs and land area needed. A compact filter system for Filtralite P was developed. Heistad et al. (2004) studied a tank filled with 6 m³ of Filtralite P operating in an up-flow mode with a life expectancy of 5 years for one family. A similar system was built in Finland, but the system encountered hydraulic problems due to a higher wastewater load compared to the system studied by Heistad et al. (2004) and was rebuilt and operated as a down-flow filter (Vilpas et al., 2005a). Another compact filter system developed in Finland consisted of a tank filled with about 1 m³ of Nordkalk Filtra P, operated in an up-flow mode (Nordkalk, 2006b). The filter material was estimated to

Table 1. Components of small scale reactive filter systems investigated in full-scale.

Pretreatment step	Reactive filter unit	Filter material
Unsaturated LWA bed, pipes	Large reactive filter bed	LWA (Filtralite P)
Unsaturated LWA bed, nozzles	Large reactive filter bed	LWA (Filtralite P)
Unsaturated LWA bed, pipes	Large reactive filter bed planted with reed	LWA (Filtralite P)
Unsaturated LWA bed, Nozzles	Compact reactive filter	LWA (Filtralite P)
Sand filter bed	Compact reactive filter	Nordkalk Filtra P
Unsaturated gravel bed+saturated willow bed	Compact reactive filter	Blast furnace slag
No pre-treatment step	Reactive filter bed planted with reed	Blast furnace slag
Unsaturated gravel bed planted with reeds	Compact reactive filter	e.g. calcite products, seashells.

Table 2. *Treatment Efficiencies of small scale reactive filter systems investigated in full-scale.*

Type of system	Reactive filter material	Design/ Life expectancy	Reported P removal	Reported BOD removal	Reported N removal
Large filter bed system ¹⁾	LWA	7–12 m ² /person 10–15 years	> 90 %	80–98 %	40–60 %
Compact reactive filter system ²⁾	Filtralite P	6 m ³ , 1 family, 5 years	99.5 %	94 %	34 %
Compact reactive filter system ³⁾	Nordkalk Filtra P	1 m ³ , 1 family, 1–2 years	>90 %	⁴⁾	⁴⁾

¹⁾ Jenssen et al. (2005)

²⁾ Heistad et al. (2004)

³⁾ Carla, personal comment (2006)

⁴⁾ The BOD and Nitrogen removal depend on the design and function of the chosen pre-treatment step. (Conventional sand filter beds are recommended.)

last between 1–2 years when located after a sand filter bed and loaded with wastewater from one family (Nordkalk, 2006b). In Luleå, two parallel compact reactive filter units with blast furnace slag and Filtralite P were located after a gravel bed planted with willows. Each filter had the same volume, 2.2 m³, and designed flow rate, 0.5 m³/d. The reactive filters were water saturated and operated in a down-flow mode (Rastas, 2006).

Design of small scale filter with clinoptilolite

Luanmanee et al. (2001) investigated a small scale multi-soil layering system consisting of an aerated 5 m³ plastic box filled with clinoptilolite (1–3 mm) and jute bags filled with a mixture of soil, jute pellets, forest floor litter and iron pellets. The system was loaded with septic tank treated wastewater.

Performance and treatment efficiency of small scale reactive filter systems

Phosphorus treatment efficiencies

The phosphorus treatment efficiencies of the large Norwegian filter bed systems have been high. Systems using porous filter materials with a high phosphorus sorption capacity have consistently removed more than 90 % of the phosphorus for more than 10 years. These systems were designed for a total surface area of 7–12 m²/person (Jenssen et al., 2005). The compact filter system using 6 m³ Filtralite P and designed for 5 years regarding phosphorus removal achieved an average phosphorus removal of 99.5 % during the first 2 years of operation (Heistad et al., 2004). The flow rate was 450–864 L/d during that period. The compact filter systems built in Finland using Nordkalk Filtra P have reduced the phosphorus concentrations of wastewater by more than 90 % during a 1–2 year period (Carla, personal communication, 2006). In these systems about 1 m³ of Nordkalk

Filtra P was loaded with wastewater from one family. When pH of the effluent dropped below 9, the reactive filter material was replaced. The treatment efficiencies of the reactive filter system using Filtralite P and blast furnace slag located in Luleå have not yet been evaluated. In Table 2, the phosphorus removal of small-scale reactive filter systems investigated in full-scale is seen.

BOD and nitrogen removal

The pre-treatment step contributes significantly to the BOD and nitrogen removal of reactive filter systems. Heistad et al. (2004) reported that the investigated compact reactive filter system removed a total of 96.4 % BOD during the first 2 years, of which the pre-treatment step alone reduced 96.1 % of the total influent BOD. The average total nitrogen removal in the system was 34.3 %, most of which was removed in the pre-treatment step (Heistad et al., 2004). Jenssen et al. (2005) reported on a BOD removal of 80–98 % for large reactive filter bed systems, with the pre-treatment step accounting for about 70 % of total BOD removal. The total nitrogen removal for these systems was 40–60 %, see Table 2. Arias et al. (2005) showed that recycling the effluent wastewater back into the septic tank in a reactive filter system increased the nitrogen removal from 1 % to 68 % when the recycled flow was 300 % of the influent flow. The wastewater recirculation improved the denitrification in the septic tank and in the pre-treatment filter.

The nitrogen treatment efficiency of the small scale multi-soil layering system investigated by Luanmanee et al. (2001), which included clinoptilolite, was significantly dependent on the aeration of the system. This indicated the ammonium adsorption mechanism was of minor importance for nitrogen removal. Also noted, clinoptilolite was principally included in the system to reduce the clogging risk and enhance the wastewater distribution.

Operational experiences of full-scale reactive filter systems

The operational success is dependent on the accurate construction of the system. Negligence during the building phase can result in operational failure. Examples of construction failures are settlements of the ground, defective pipe connections or ignorance of the pre-treatment step. Apart from this, the advantage of reactive filter bed systems is a robust design requiring little maintenance (Jenssen et al., 2005). However, problems with wastewater distribution into the pre-treatment step have occurred due to clogging of the distribution pipes (Rastas, 2006) or the nozzles (Arias and Brix, 2005b; Hellström and Jonsson, 2005). Problems with the pumping devices have also been reported (Arias and Brix, 2005b; Maelum and Kähler, 2005; Vilpas et al., 2005a). Clogging of the pre-treatment filter and the reactive filter material may also occur due to cementing effects of the chosen filter material (Vilpas et al. 2005a; Westholm, 2006), deterioration of the grains (Nguyen and Tanner, 1998) or a too high influent concentration of suspended solids (Carla, personal communication, 2006).

Effluent pH

High effluent pH from reactive filter units with Filtralite P and Filtra P are due to the alkaline compounds of the materials. The initial pH from full-scale experimental Filtralite P systems was 12.7 (Føllesdal, 2005), which decreased to 11 after several months of operation. Other reactive filter materials with alkaline components would also cause a high effluent pH.

This high effluent pH may be a recipient problem, if the effluent recipient is small. However, the efficient virus and bacteria inactivation observed by Heistad et al.

(2004) in a Filtralite P system was an effect caused by the high pH.

Leakage of sulphuric compounds

Due to the high content of reduced sulphuric compounds in blast furnace slag (1–2%), sulphuric compounds may oxidise and leach out in the effluent when used as a reactive filter material. In a pilot scale study, the release of sulphuric compounds was considerable, especially in the initial operation phase (Rastas, 2003); see Figure 4.

Therefore, the risk of polluting groundwater with sulphuric compounds exists if using blast furnace slag as a reactive filter material. It is important that a blast furnace slag filter be located away from drinking water sources to guarantee the drinking water quality (Hedström and Rastas, 2006). Malodours due to sulphuric compounds might also be a problem when using blast furnace slag.

Protons are formed during the oxidation of the sulphuric compounds in the blast furnace slag, possibly resulting in a pH decrease (Kanschä, 1996). However, the slag has a pH-buffering capacity due to the contents of alkaline oxides (Lindgren, 1998). Therefore, the impact of blast furnace slag on the effluent pH is difficult to predict if using the slag as a reactive filter material.

Sorbed nutrients for recovery and cultivation

To recover sorbed phosphorus and ammonium for cultivation purposes, the exhausted filter material can be applied onto arable land.

Plant availability

Kvarnström et al. (2004) performed a study where almost all inorganic phosphorus that sorbed to LWA material was shown to be easily soluble, mobile and available for plants. In another study, Filtralite P served as a somewhat slow-release phosphorus fertiliser (Nyholm et al., 2005). Burned lime, LECA, soil from a spodic B horizon, sand, calcium carbonate, opoka, Polonite, amorphous and crystalline blast furnace slag were investigated by Hylander and Siman (2001) and Hylander et al. (2006). Blast furnace slag was found to be the most suitable sorbent from an agricultural viewpoint due to the sorbed phosphorus that was readily released to plants when applied to soils. Ammonium saturated zeolites were suggested to be used as a nutrient source that could be spread on the arable land (Bolan et al.,

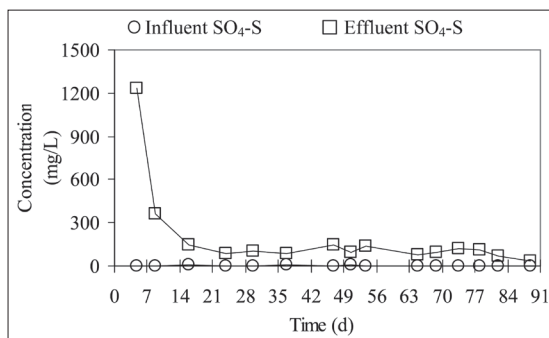


Figure 4. Influent and effluent concentrations of $\text{SO}_4\text{-S}$ in a pilot scale experiment with blast furnace slag as a reactive filter material (Rastas, 2003).

2004). Ammonium loaded clinoptilolite was investigated as a fertiliser in pot experiments and no difference in yield was observed between fertilising with clinoptilolite or ammonium sulphate (Perrin et al., 1998).

Liming effect of exhausted filter materials

Due to the lime content of several reactive filter materials for phosphorus sorption, these exhausted sorbents have a liming effect if applied to agricultural fields which can improve the cultivation conditions. Nyholm et al. (2005) found that Filtralite P had a liming value, and the blast furnace slag produced at SSAB in Oxelösund has been certified as a liming agent for ecological agriculture (KRAV, 2006). Exhausted Filtra P also has a liming effect (Nordkalk, 2006a). However, the liming effect of exhausted sorbents on arable land may be too high for cultivated crops (Hylander and Siman, 2001) and should be considered when using the exhausted sorbents as fertilisers.

Content and sorption of heavy metals

A low heavy metal content of unused reactive filter materials is important if an exhausted filter material should be used for fertilising purposes. The heavy metal content of manmade reactive filter materials can be regulated by the choice of raw materials. For industrial by-products, such as blast furnace slag, the heavy metal content depends on the industrial process. The soluble amounts of many heavy metals from blast furnace slag is lower compared to natural rock materials due to the low content of these elements in slag (Tossavainen and Forssberg, 1999; Tossavainen and Forssberg, 2000). Vanadium is the minor element that may leach out in larger amounts (Tossavainen and Forssberg, 2000).

Some reactive filter materials have been examined for sorption of wastewater phosphorus or ammonium, and also studied regarding heavy metal sorption. Opoka and zeolite showed high sorption capacity of Cu and Zn (Färm, 2002). Blast furnace slag proved to be an appropriate sorbent for ionic Pb removal (Dimitrova, 2002) and was found to remove Cu, Zn and Ni (Dimitrova, 1996; Kietlinska and Renman, 2005). In the same study, Polonite proved to efficiently remove Mn, Fe, Zn and Cu. Gupta et al. (1997) found slag from blast furnace waste material to be an effective adsorbent for removal of Zn and Cd. LWA filters accumulated Zn, Ni, Cr, Co and V (Jenssen et al., 2005), though it was concluded that the amounts of accumulated heavy metals were low.

Due to the possible accumulation of heavy metals in reactive filter materials, it is important that wastewater loaded into reactive filters contains as low concentra-

tions of heavy metals as possible. Otherwise, the exhausted filter materials may not be used for cultivation purposes.

The future of reactive filters for small wastewater treatment system

System development

Reactive filter systems have the potential for small scale wastewater phosphorus removal in Nordic countries. Due to new regulations for small wastewater treatment systems with defined reduction rates (Finlex, 2003) and demands for nutrient recovery (SEPA 2006), the demand for more efficient systems will be greater. The large filter systems with Filtralite P have proved to be robust, with little maintenance and high treatment efficiency (Jenssen et al., 2005). However, to facilitate the exchange of exhausted filter material (Arias et al., 2003a), decrease the size of the systems and decrease the building costs (Heistad et al., 2004), more compact systems should be developed.

Further research on reactive filter materials for phosphorus sorption

Westholm (2006) concluded in a literature review that wollastonite, slag materials and LWA-products were promising reactive filter materials concerning phosphorus sorption and hydraulics. Polonite and Nordkalk Filtra P also have shown potential for phosphorus sorption. However, further development and investigations of reactive filter materials are needed. LWA materials are the only materials to have been largely investigated in full-scale applications. Full-scale investigations of other materials, such as blast furnace slag and Polonite, are required to investigate the materials with respect to the hydraulic capacity and the influence of wastewater on the phosphorus sorption. Furthermore, for all studied phosphorus sorbents, sorption during long-term operation is uncertain. Longevity studies of the materials must therefore be carried out. Resting periods of reactive filters were shown to regenerate the sorption capacity of the electric arc furnace steel slag (Drizo et al., 2002) and Filtralite P (Adam et al., 2005), a phenomenon that should also be investigated further. Studies on the leakage of sulphuric compounds when using blast furnace slag as a reactive filter material are also urgently needed. Optimisations of pre-treatment steps are necessary to achieve more compact systems (Jenssen et al., 2005).

Since phosphorus is a non-renewable resource (Schnug et al., 2003), wastewater phosphorus should be recycled and used in cultivation (SEPA, 2002). Hence,

the risks and opportunities of using exhausted filter materials for fertilising purposes must be elucidated and investigated further. Desorption and reclamation of sorbed nutrients on reactive filter materials are also interesting to study, especially if the filter materials are not accepted for spreading on arable land. Finally, system analyses, such as LCA or exergy analyses of sorbents, are relevant to evaluate and compare different filter materials.

The potential for ammonium adsorption

The future use of ammonium sorbents for small scale wastewater treatment is uncertain. Even though the ammonium adsorption capacity for, e.g., clinoptilolite is at least as high as the phosphorus sorption capacity of many phosphorus sorbents, the required volume of the ammonium adsorbent is larger due to higher wastewater ammonium concentrations compared to phosphorus. This means that either the reactive filter units for ammonium adsorption must be larger than corresponding systems for phosphorus sorption, or they must be exchanged more often. If the wastewater nitrogen in small scale wastewater treatment systems will not be reused, it may be more appropriate to develop the design of the reactive filter systems for, e.g., nitrification-denitrification to reduce the effluent concentrations of nitrogen compounds (Arias et al., 2005). However, ammonium adsorption may be an alternative during the cold season if the efficiency of the biological processes decreases (Jenssen et al., 1991).

Conclusions

- Many reactive filter materials for phosphorus sorption have been evaluated in laboratory experiments, though few materials have been investigated in full-scale applications.
- The Lightweight aggregate material Filtralite P is the most studied reactive filter material in full-scale, used in more than 200 systems. Nordkalk Filtra P has been used in about 80 full-scale systems. Both materials have shown good treatment results with respect to phosphorus sorption.
- Blast furnace slag and Polonite are reactive filter materials that have shown promising phosphorus sorption results in laboratory investigations. However, further full-scale studies must be conducted before they can be recommended for wastewater treatment.
- Different types of zeolites, such as clinoptilolite, greatly adsorb ammonium.
- A reactive filter system should at least consist of a sludge separation unit, a pre-treatment step and a reac-

tive filter unit. The pre-treatment step contributes to the BOD and nitrogen removal of the treatment system and reduces suspended solids and organic matter in the wastewater to prevent clogging of the reactive filter unit.

- Small, compact systems should be developed to decrease the construction costs, decrease the area needed and facilitate the exchange of the exhausted materials.
- Many reactive filter materials investigated for ammonium and phosphorus also sorb heavy metals. Heavy metal sorption may limit the reuse of the sorbed nutrients.

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- Personal communication:
 Vibeke Rystad, Maxit Group/Filtralite, Oslo, Norway (2006)
 Manne Carla, Nordkalk, Pargas, Finland (2006)

