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Review

Substrates for phosphorus removal—Potential benefits for on-site wastewater treatment?

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ABSTRACT

A large number of substrates potential for removal of phosphorus (P) in wastewater has been reviewed. The substrates consist of natural materials, industrial by-products and man-made products. Most substrates have been investigated in batch and column studies in the laboratory; others have also been tested in field trials. The results from these investigations vary, but a few substrates, e.g. wollastonite, slag material and, to some extent, light weight aggregate products, have demonstrated promising properties with regard to P-sorption capacity and hydraulics. The problems of normalisation of data are discussed, as well as the substrates potential benefits for on-site wastewater treatment.

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1. Introduction

Discharge of wastewater is one of the major sources of phosphorus (P) entering streams, lakes and other water bodies, causing undesired environmental problems such as eutrophication and algae bloom. Important sources of P-pollution in Sweden and in other European countries are single households in rural areas discharging inadequately treated wastewater (Johansson, 2002; Vymazal et al., 1998). These households have to rely upon low-cost small-scale wastewater treatment systems, for instance soil infiltration systems and constructed wetland systems (CWS).

Constructed wetlands have gained particular attention as attractive solutions for wastewater treatment and have accordingly been used world over (Hammer, 1989; Cooper and Findlater, 1990; Moshiri, 1993; Bavor and Mitchell, 1994; Kadlec and Knight, 1996; Vymazal et al., 1998; Okurut et al., 1999; Brix et al., 2001). These systems have proved to remove P, and different P-removal mechanisms taking place in CWS have been identified, for instance assimilation and release by vegetation and micro-organisms, but also sorption to soils and sediments (Reddy et al., 1999). Other onsite treatment systems based on sorption to soils and other substrates have also been regarded as feasible for wastewater treatment. Among these, traditional sand filters and, more recent, filter modules can be mentioned (Baker et al., 1998; Brix et al., 2001). The latter can be part of treatment systems to be designed or even be included in already existing ones.

Sorption of phosphorus to the substratum has been recognised as one of the most important removal mechanisms for more than a decade (Richardson, 1985). Traditionally, locally available materials such as sand and soils have been used as substrate for P-removal. In many cases, these substrates have been used without any knowledge of the P-retaining capacities, even though some recent studies have aimed at investigating the P-sorption capacity of Danish sands of different origin (Arias et al., 2001).

In recent years, research has been directed to selection of substratum due to the fact the P-sorbing capacity of the substratum is a crucial parameter for the P-removal (Drizo et al., 2002). Since the sorption, e.g. adsorption and/or precipitation mechanisms, is a finite process, it is an important factor to consider when selecting substrates for potential use in CWS or in other filter-based systems. Other reasons for searching for alternative substrates are that local substrates are not always available to a reasonable cost (Geohring et al., 1995; Sakadevan and Bavor, 1998).

A large number of studies have, therefore, been carried out on different P-sorbing materials for potential use in CWS or in other small-scale filter systems (Johansson Westholm, 2002). Scattered research has been conducted on a wide variety of potential substrates. Some of the reported materials include minerals and rocks, soils, marine sediments, industrial by-products from the steel and mining industries and man-made products.

The overall aim with this paper is to give an overview of the literature on P-sorption by different substrates. Further on, the aims are to discuss a possible normalisation of results, as well as discuss whether the filter substrates are beneficial for on-site wastewater treatment.

2. Results and discussion

According to the literature reviewed, the substrates tested can be divided into three categories, viz. natural materials, industrial by-products and man-made products (see Table 1). Natural materials include minerals and rocks, soils and marine sediments. These substrates can be used as substrates without any pre-treatment, but they can also be used after a slight pre-treatment which is carried out in order to optimise the P-sorption capacity. In this survey, slight pre-treatment of materials includes grinding and/or heating of the material. Industrial by-products are generated during a large variety of activities in society. Now and then, the industrial by-products have been deposited at landfill sites since there have been no use for them. When there has been a shortage of natural resources, industrial by-products have attracted attention as potential candidate materials for P-removal. Several kinds of industrial by-products can be distinguished—by-products from the steel industry, by-products from the mining industry and by-products from the power plant industry. Different man-made products have also been investigated as substrates for P-removal. In most cases, these substrates can be classified as lightweight aggregates. These were originally intended for insulation purposes, but have nowadays been designed for an optimal P-removal.

2.1. *Filter substrates*

Different types of naturally occurring materials have been tested world-wide—minerals and rocks, soils and marine sediments. These can be used as substrates without any pre-treatment, but they can also be used after a slight pre-treatment which is carried out in order to optimise the P-sorption capability. In this survey, slight pre-treatment of materials includes grinding and/or heating of the material.

2.1.1. *Minerals and rocks*

Dolomite and *dolomite sand* have been tested for P-removal in a number of studies both in the laboratory and in the field. From laboratory investigations it was suggested that the major removal mechanism was adsorption to the surface. In field trials, other removal mechanisms than adsorption, e.g. biological removal processes, are likely to have an impact on the retention of P. From experiments carried out in the field, P was removed by 30–50% when dolomite or dolomite sand were included in CWS. Solely one study (Pant et al., 2001) tried to distinguish between removal mechanisms, e.g. removal of P by substrate and other possible mechanisms. Irrespective of removal mechanisms, the results from field trials indicate