



Filtration curtains for phosphorus harvesting from small water bodies



Agnieszka Karczmarczyk*, Agnieszka Bus, Anna Baryła

Faculty of Civil and Environmental Engineering, Warsaw University of Life Sciences – SGGW, Nowoursynowska Street 166, 02-787 Warsaw, Poland

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ABSTRACT

The reactive material (RM) Polonite® in the form of suspended filter (Suspended Reactive Filter, SRF) was used in the study. The experiment was carried in laboratory in hydraulic block of 1 m width and 2 m length. Three curtains consisted of eight suspended bags filled with the reactive material were used. The total mass of the reactive material was 1200 g per experiment. The ratio of the mass of the reactive material to the water volume in hydraulic block was 3:1 (g:dm³). The initial phosphorus concentrations were 1.439; 1.852; 2.384 and 3.012 mg P-PO₄ dm⁻³ in different tests, corresponding to the polluted surface water in Poland. The results showed successive reduction of phosphorus from water in the time of experiment and number of cycles when water passed through the system of curtains of SRF. Regardless of the initial concentration, SRF decreased level of P-PO₄ in solution of 0.517 ± 0.018 mg dm⁻³ at average. Base on the results, the nomogram supporting practical implementation of the RM Polonite® has been created for the estimation of the mass of the RM depending on the initial and desired final concentration of phosphorus in water.

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1. Introduction

The pollution of water bodies in the rural landscape comes from non-point and dispersed sources (surface run-off, discharge from drainage systems, spills from leaky septic tanks, effluents from the local sewage treatment plants, etc.). The point sources can be easily reduced by the “end of pipe” solutions in the place of their formation. The non-point sources, however, are difficult to catch and uncontrolled leaking into ditches and small streams, and then into the rivers and the seas. Especially, drainage ditches serve as primary conduits for drainage and agricultural runoff and therefore carry pollutants from agroecosystems to downstream water bodies (Needelman et al., 2007).

Particularly troublesome to the aquatic environment are nutrients (nitrogen and phosphorus), that in surface waters cause an eutrophication, resulting in a decreasing of their quality and losses of water suitability for use in water supply, animal breeding, fish farming and recreation. In freshwater bodies eutrophication is usually thought to be controlled by phosphorus inputs (Schindler et al., 2008). Agriculture is a major contributor of P loadings to surface waters in European catchments and globally (Withers et al., 2015). Losses of P in leaching and runoff across the EU (calculated for the EU15) were of 0.1 T g P yr⁻¹ (Ott and Rechberger, 2012).

Contemporary trends of surface water protection against non-point sources of pollution include solutions such as: creating buffer zones (Vought et al., 1995; Izydorczyk et al., 2013); wetlands (Kynkäänniemi et al., 2013; Tonderski et al., 2013); P-removal structures (Penn et al., 2012); drainage ditches with aquatic plants (Liu et al., 2013) and P-sorbing materials (Penn et al., 2007); biogeochemical barriers (Izydorczyk et al., 2013) and other filters (Kirkkala et al., 2012; Tonderski et al., 2013). Uusitalo et al. (2015) introduced the simple type ferric sulfate dispenser for reducing concentrations of dissolved P in stream runoff, especially in early spring period, when other P-removal structures are still frozen. Takeda et al. (2010) proposed the method using iron-oxidizing bacteria and woody biomass as a carrier. This method has also a potential of P recovery, as approximately 70% of adsorbed P was available for plant uptake. Sibrell et al. (2009) achieved the removal of 60–90% of the phosphorus from agricultural wastewaters using adsorption media prepared from acid mine drainage sludge (Feroxysorb). All these measures are expected to limit the input of pollutants into water bodies or limit the cumulative outflow from ditches to their receivers. Also, the variety of BMPs, e.g. no spread zones around water courses, conservation buffer zones for highly erodible soils, constructed wetlands, plant vegetation and ditch clearance are necessary for controlling pollutant transport in drainage ditches (Liu et al., 2013; Kleinman et al., 2015).

One of the measures supporting purification of P-polluted water bodies is to use the reactive materials (RMs) in the form of barriers or filters of different structures (Penn et al., 2007; King et al., 2010;

* Corresponding author.

E-mail address: agnieszka.karczmarczyk@sggw.pl (A. Karczmarczyk).

Frątczak et al., 2012; Kirkkala et al., 2012; Tonderski et al., 2013). Wide variety of different P-reactive materials is potentially available to remove P from agricultural runoff. A comparative studies of P-RMs used in wastewater treatment were conducted by Johansson Westholm (2006), Cucarella and Renman (2009) and Klimerski et al. (2012). Not all of RMs, tested for P removal from domestic or municipal wastewater, are also suitable to remove P at low concentrations which are usually found in drainage ditches or agricultural streams (Karczmarczyk et al., 2014). Some of RMs can even release P at low concentrations in water. That means, that the behavior of each RM should be tested at low P concentrations before the application for agricultural runoff treatment.

Preventing nutrient outflow to water bodies is the technical problem, consisting of finding where and how the measure can be easily and economically implement. Reactive materials were preliminary implemented to remove phosphorus from surface water in P-removal structures, geochemical barriers and ditches filters (Penn et al., 2007; 2012; Bryant et al., 2012; Kirkkala et al., 2012; Izydorczyk et al., 2013). We have proposed an alternative way of the application of RM in the form of the curtain of filters suspended in the water (Suspended Reactive Filter, SRF). This form of application allows the direct contact of the sorbent with the water and is dedicated to be used in small agricultural streams, drainage ditches and standing water, where water stagnation or slight flow create favorable conditions and time for contact of reactive material with polluted water.

There is no other raw source of phosphorus than the non-renewable resource in phosphate rocks, and there is not known substitute for phosphorus in agriculture. Availability of phosphorus ensures the food security. From the other side, phosphorus concentration in freshwater and terrestrial systems has increased by at least 75% in the last half-century (Bryant et al., 2012). The solution is to reuse phosphorus from waste streams: organic waste, sewage and sewage sludge. Considerable attention should be given to prevent loss of phosphorus from agriculture. The challenge for the future will be to develop methods of obtaining phosphorus accumulated in the soil (MacDonald et al., 2011), sediments (Bennett et al., 2001) and in the water environment. The goal of presented work follows the idea not only to remove but to “harvest” phosphorus from water bodies. Harvested P can be use as a fertilizer, and thus will reduce the use of P coming from non-renewable resources. The aim of the study was to evaluate the P removal efficiency of the reactive material Polonite[®] implemented in the innovative form of suspended filters (SRF). The Polonite[®] is one of the most examined RMs for phosphorus removal, with proved active sorption at low P concentrations (Karczmarczyk et al., 2014) as well as high recycling potential of sorbed P in agriculture (Hylander et al., 2006; Cucarella et al., 2008).

2. Materials and methods

2.1. Material

The reactive material (RM) Polonite[®] is well known P-sorbent discovered in Poland by professor Zygmunt Brogowski (SGGW) and further developed by researchers from KTH in Sweden (Brogowski and Renman, 2004) and SGGW in Poland (Karczmarczyk, 2000). It was evaluated as the phosphorus sorbent in different environmental applications e.g. wastewater treatment (Renman and Renman, 2010), landfill leachate treatment (Renman, 2008) and the green roof run-off treatment (Karczmarczyk et al., 2014).

The RMs are the materials that chemical composition creates the potential for the selective formation of compounds with the desired pollution. The reactive materials for the removal of phosphorus contain Al, Fe or Ca in active form (Drizo et al., 2000; Dunne

Table 1
Characteristics of reactive material used in the study.

Reactive material	Polonite [®]
Physical properties	
Grain size [mm]	2.0–5.0
Density [g cm ⁻³]	0.78
Porosity [%]	38.0
Chemical composition [% of tot. mass]	
SiO ₂	55.1
CaO	23.9
Al ₂ O ₃	5.7
Fe ₂ O ₃	2.1
Apparent* sorption capacity [mg g ⁻¹] (Bus and Karczmarczyk, 2014)	
* From the Langmuir isotherm	12.3

et al., 2008; Johansson Westholm, 2006; Renman and Renman, 2010; Vohla et al., 2011; Yin et al., 2011; Mateus et al., 2012). The Polonite[®] consist of the thermally activated calcite. This material is of natural origin (calciferous bedrock), and in different studies different lots of Polonite[®] were used. They varied in Ca content and following P-sorption capacity (Brogowski and Renman, 2004; Bus and Karczmarczyk, 2014). Basic parameters characterizing the Polonite[®] used in this study are summarized in Table 1.

The novelty of this study is the use of reactive material in the form of curtains consisted of filter bags filled with the RM and suspended in the flowing water. Bags were made of polyester textile with a 2 mm mesh. The shape of the bag allows for easy filling and emptying filters. Bags were attached by the inelastic cord to the rod based on the edges of the watercourse. The solution is called suspended reactive filter (SRF) and is the base of patent application (P. 403571) (Karczmarczyk and Bus, 2013).

2.2. Experimental design

The experiment was conducted in the laboratory conditions, on the hydraulic block of the length of 2 m and the width of 1 m. Filling up the block ranged from 0.14 m (inlet) to 0.16 m (outlet). The block with the tank and pump were operated in a closed system. Three parallel suspended filters curtains with reactive material were installed in the block. Each curtain consisted of eight filters in a row. The distance between curtains amounted 0.7 m. In total 24 filter bags were used with a total weight of 1200 g of the reactive material. The scheme and photo of the experiment are shown on Figs. 1 and 2. Thermal imaging techniques verified the uniformity of water flow through the hydraulic block (Fig. 2).

The block and the tank were filled with a solution prepared from KH₂PO₄ and a tap water. The initial concentrations of P-PO₄ amounted 1.439 mg dm⁻³; 1.852 mg dm⁻³; 2.384 mg dm⁻³ and 3.012 mg dm⁻³. These values correspond to phosphorus concentrations encountered in polluted surface waters.

During the experiment, samples were taken at two control points (1—inlet, 2—outlet) and analyzed for phosphorus and pH (Fig. 1). The water flow during the experiment varied between 228 and 252 dm³ h⁻¹ (average 240 dm³ h⁻¹). The total capacity of the system was 470 dm³. During the experiment, the volume of water was maintained at 400 dm³ in order to keep the ratio of the mass of the reactive material to the volume of solution at 3:1 [g:dm³]. Determination of phosphorus concentration was performed by flow injection analysis on analyzer FIASStar 5000. Control of pH was carried out using a pH meter LF-340.

3. Results

The set up of the experiment (Fig. 2) simulates the small stream or ditch transporting the water polluted with P originating from non-point sources (agricultural runoff) and dispersed point

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