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Oil removal from runoff with natural sorbing filter fillers

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ABSTRACT

The aim of this paper was to investigate the ability of Lithuanian sheep wool waste and reeds (*Phragmites australis*) to absorb oil from runoff when it flows through filters filled with these materials. The third material that was analysed, the synthetic sorbent Fibroil, was chosen for comparing the results. The laboratory experiments were performed in several stages, with the following being filtrated: tap water with a diesel admixture, road runoff contaminated with oils, and also suspended solids. The significance of this work is due to the high runoff filtering rate (∼10 m/h) and high oil concentrations in the runoff (50–230 mg/L) used in the experiment. In these cases the use of sorbents is limited. Wool waste and reed (*Phragmites australis*) fillers are quite efficient (98–99%) in oil removal from runoff at a 10 m/h filtering rate. However, wool fillers clog up quickly. Reeds of the genus *Phragmites australis* are a natural source for the production of oil sorbents. The results obtained in this experimental work can be used in the design of equipment for the treatment of oil-contaminated runoff from gas stations as well as sullage from roads and tunnels.

1. Introduction

The environment is contaminated with road runoff from watertight urban areas. The greatest runoff contaminants are total suspended solids (TSS) and oils (German and Svenson, 2005; Mimi, 2008; Paulauskiene et al., 2009). Oils that reach groundwater or surface water bodies after rain are toxic and negatively affect water quality (Saito, 2010). The surface of suspended solids adsorbs phosphorus and nitrogen compounds, heavy metals and other contaminants which may cause critical changes in aquatic ecosystem. These changes have a direct impact on human health, aquatic flora and fauna (Pitt et al., 2002; Nolde, 2007; Brown and Peake, 2006). According to Lithuanian legislation, the highest concentrations of oil and suspended solids in discharges into runoff networks that are allowed are 300 mg/L for TSS and 30 mg/L for oil. When road runoff is released directly into the natural environment, the allowable concentrations are: 50 mg/L for TSS and 7 mg/L for oil. Oil concentration in runoff collected from urban areas is normally between 10 and 35 mg/L. However, it may be much higher depending on the type of area it is collected from (Pitt et al., 2002; Paulauskiene et al., 2009). Oil concentration in runoff collected from highways and motorways usually reaches about 50 mg/L (and in exceptional cases even higher oil concentrations, reaching 400 mg/L, may be observed) (Muhammad et al., 2004). The average oil concentration estimated at gas stations and garages runoff also exceeds 50 mg/L (Khan et al., 2004). Considering the negative road runoff effect on aquatic ecosystems, it is clear that discharge of such runoff into surface water bodies is dangerous, as oil concentration is often more than ten times the allowable 7 mg/L limit.

Road runoff produced from gas stations and car parking areas is usually treated with oil separators. The structure of the separators consists of settlement tanks and filters that may be coalescing and sorption (Herrmann and Schmida, 2000; Adebajo et al., 2003; Muhammad et al., 2004; Husein et al., 2008; Fuerhacker et al., 2011; Shrestha and Brodie, 2011). Sorption filters are only effective when treated runoff is kept in a filler of filter for a sufficient amount of time (Teas et al., 2001; Rajakovic et al., 2007; Ali et al., 2011). However, in runoff treatment the water flow is instantaneous. The filtering rate constantly grows; therefore, the time that runoff is kept in the filter drops (Zhu et al., 2010). When it rains heavily, the rate of the runoff filtering through the sorption filter may reach 10–20 m/h, depending on the type of area. In this case, oil sorption in the filter filler is only partial; thus, higher than allowable oil concentrations may remain in the filtrate. If runoff flow rate are high, suspended solids have no time to settle in oil separators settlement tanks; thus they get into sorption filters and clog them. As a result, the oil sorption efficiency decreases. Earlier studies have shown a need to improve the design of oil separators (Mazeikiene et al., 2005; Baltrenas and Branvall, 2006).

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An ideal sorbent designed for oil removal should have the following properties: oleophilicity, hydrophobicity, high sorption capacity, buoyancy, economy and accessibility (Yang et al., 2011). Between sorbents offered by producers today, the most popular are synthetic sorbents, e.g. Fibroil made from polypropylene and polyethylene fibre with a limestone supplement (Rengasamy et al., 2011). However, synthetic sorbents are expensive and their recovery pollutes the environment; thus, they are usually used to clean up oil spills when oil concentration is sufficiently high (Deschamps et al., 2003). Now a growing number of scientists are writing about the use of natural organic sorbents for runoff treatment, as they are more acceptable than synthetic sorbents from an environmental point of view. These sorbents are more economical, and can be easily dissolved, while their recovery options are promising (Annunciado et al., 2005). The only expenses for this kind of sorbents are collection and preparation costs, because they are usually available in local areas, and, therefore, their price can be competitive (Khan et al., 2004). Different organic materials have been investigated for oil sorbtion from water or runoff such as peat moss, vegetable fibres and their composites, sawdust, sisal fibre (*Agave sisalana*), coconut fibre (*Cocos nucifera*), vegetable-sponge (*Luffa cylindrica*), silk threads, mucor (*Mucor rouxii*), and kapok fibre (*Ceiba pendatra*) among others. Sorption filter fillers made from these materials are 42–98% efficient in removing oil products (Deschamps et al., 2003; Baltrenas and Branvall, 2006; Cambiella et al., 2006; Lim and Huang, 2006; Rahmah and Abdullah, 2010; Cojocaru et al., 2011). Although organic sorbents are less efficient in oil removal, they should not be underestimated (Moriwaki et al., 2009; Srinivasan and Viraraghavan, 2010; Wang et al., 2012; Svegl et al., 2013). Sorbent materials commonly can be found in local natural resources or industrial waste (Maiti et al., 2011). In Lithuania these local materials could be reeds or sheep wool waste.

2. Methodology

2.1. Sorbents

The aim of this study was to investigate the ability of Lithuanian sheep wool waste and reeds growing near the lakesides (*Phragmites australis*) to absorb (or adsorb) oil from runoff when it flows through filters filled with these materials. For the efficient use of sorbents in runoff treatment, it is essential to focus on studies on sorbing filter fillers and the necessary filtration conditions. The natural sorbents capacity to sorb oils and their hydraulic conductivity must be examined before they are used in oil separators.

Three sorbing materials were chosen for the experiment: wool, reeds (common reed) and synthetic sorbent Fibroil for comparison purposes. The wool used for the experiment was a wool waste part of natural fibre from a Lithuanian sheep breed (the Lithuanian Black-Headed Sheep). The wool mass in the filter column was 36.03 g. The other investigated material was common reed (Lat. *Phragmites australis*), a species of the Poaceae plant family. The plant grows up to 100–400 cm. It is found on river and lake shores, in wetlands and in roadside ditches. The thick patches of reeds grow in the area of the Curonian Lagoon. For the experiment described in this paper, reeds were taken from Rekyva Lake in Lithuania. Long-reed stems were cut into pieces before placing them into the filter column in the laboratory. Two reed fractions have been analysed: a 5–7 cm length of dried reed (Reed I) and a 1–1.5 cm length of reed collected in autumn (Reed II) that was not dried. The third analysed material – a synthetic sorbent Fibroil – was chosen for comparing the results. Fibroil is a fibrous adsorbent material made of polypropylene and polyethylene fibre with a supplement of limestone, and it is recovered by burning. This material is protected from ultraviolet radiant exposure, is waterproof and non water-absorbent, and is also suitable for exteriors (properties as indicated by the producer).

2.2. Experimental setup

The filtration equipment was installed in the laboratory at the Department of Water Management at Vilnius Gediminas Technical University. The experimental setup is shown in Fig. 1.

Road runoff or tap water was poured into the tank (1). The pump (12) carried it to the tank (2), where a stable liquid capacity was maintained, with ensuring steady flow rate in the pipe (4) at an incline of 3°. The rate was controlled by opening the valve in line with the filtrate flow. The rate was measured every 10 min. Diesel fuel from the vessel (3) was inserted by peristaltic pump into the running liquid at a rate at which the initial oil concentration (P_i) was reached before going through the sieve at the end of the pipe, where samples were taken. Afterwards, road runoff or tap water with initial oil concentration was provided at an equal load through the sieve to the filter column (6) with a cross-sectional area of 0.005 m^2. The water was filtrated through a 10 or 20 cm high filler layer, as these height values are usually used in oil separators. Filtering rates of 10 and 15 m/h were chosen for the experiment. Filtrate and mixture samples from the hose (9) were put in jars with a 0.5 L capacity before putting it in the filter column every ten minutes. Contamination in these samples was measured by estimating oil and suspended solids concentrations. Pressure losses in the filter column were measured by a piezometer (10). Each individual filtration experiment was performed with a new filler of filtering material. The parameters were measured 3 to 4 times. Errors of sample taking and the precision of the measuring tools were estimated. After the experimental work, a statistical analysis of the results was prepared by eliminating unreliable values above the 95% confidence interval.

2.3. Analytical methods

At the beginning of the experiments, the concentration of suspended solids in runoff was measured in the laboratory of the Department of Water Management at Vilnius Gediminas Technical University. It was measured by filtering runoff samples through paper filters and drying sediments at a temperature of 105 °C until their weight became constant (the experiments were carried on according to the normative environment protection document LAND 46-2002).

Oil concentration in samples was measured in the Ecologic Supervision Laboratory at the private limited company UAB Grinda. This laboratory is certified by the Environmental Protection Agency of the Republic of Lithuania. The concentration of generic oil (nonpolar and poorly polar carbohydrate extracted with hexane) was determined following the ISO 9377-2:2000 standard (LAND 49-2002 Water Quality). Infrared spectrophotometry method to determine mineral oil (oil products). The device that was used, an oil analyser AN-2, can measure a range of 0.04–1000 mg/L with a ±2% ascending accuracy.

The results were calculated using formulae shown below.

Oil amount (mg) in runoff before the filter was calculated according to the formula:

$$P_{\text{inf}} = \sum_{i=1}^{n} P_i \cdot Q_i \cdot \Delta t_i, \tag{1}$$

where P_i = oil concentration before the filter at each time interval (mg/L); Q_i = water flow rate at each time interval (L/min); Δt_i = interval time of sampling (min).