GEOLOGIJA. 2007. No. 59. P. 72–76

Engineering Geology • Inžinerinė geologija • Инженерная геология

Improvement of storm water runoff treatment system with natural mineral sorbent

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Brannvall E. Improvement of storm water runoff treatment system with natural mineral sorbent. *Geologija*. Vilnius. 2007. No. 59. P. 72–76. ISSN 1392-110X

Rain and snowmelt water contaminated with petroleum products, heavy metals and other pollutants flows into roadside drainage ditches. The proposed system of runoff treatment contains a sorbtive of 0.2 m layer sand and 10% of natural zeolite. The soil surface of the runoff treatment system is overgrown with grass. The efficiency of the proposed infiltration-grassy-A-line type runoff treatment system with a natural zeolite layer is approximately 10% higher than of the ordinary runoff treatment system with a sand layer alone.

Key words: highway, natural sorbent, storm water runoff, treatment system

Received 16 April 2007, accepted 04 June 2007

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INTRODUCTION

Rain and snowmelt water contaminated with petroleum products, heavy metals and other pollutants flows into a roadside drainage ditch. In Lithuania, these drainage ditches are not functional and do not protect groundwater from pollution. The runoff treatment systems are technically and morally obsolete; from them, polluted waterflows into the surface water.

Highway runoff contains various pollutants such as heavy metals (Pb, Zn, Cu, Mn, Ni, Cr, Cd Sn, Mo, V, etc.) that originate from the wear of vehicle parts, ties and road surface, are present in the oil and petroleum additives and in petroleum products (Sansalone, Buchberger, 1997; Davis, Shokouhian, 2001). The runoff treatment methods usually are associated with a huge amount of water in the pollutant retention / detention ponds, by letting the pollutant to settle or separate before the water gets into the wastewater system. It allows to reduce the concentration of heavy metals associated to the solid phase (Yousef et al., 1990; Pontier et al., 2001). However, the runoff treatment methods are less effective in the case of metals related to the soluble phase of storm water runoff. The clay layer in the pollutant retention / detention ponds could be used for the immobilisation of soluble fraction of the heavy metals. Certain species of reeds in a wetland system could be used as well (Hares, Ward, 1999; Shutes et al., 1999).

A natural material in which sorption is carried out by ion exchange could be used as an additional storm water treatment means through the exchange of any toxic ion by sodium, calcium or manganese cations. This technology could reduce the concentration of heavy metals in storm water runoff by filtrating it through the material. The sorption process of the material is based on ion exchange and later on regenerating it for the further use. Natural zeolite (Fig. 1) is a very suitable material for removing pollutants from soil and water and shows a very high ion exchange capacity (Kesraoui-Ouki et al., 1994; Curkovic et al., 1997).

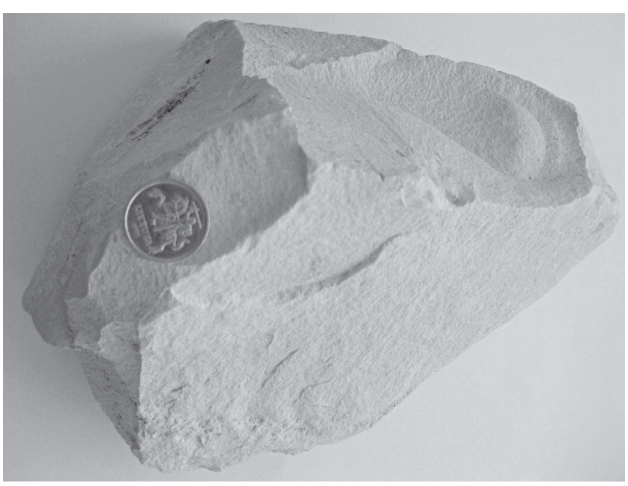

Fig. 1. Natural zeolite
1 pav. Gamtinis ceolitas

METHODS

Soil samples were analysed by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES, Perkin Elmer Otima 2000 DV) for Cr, Cu, Pb and Zn in a liquid phase.

Five different initial concentrations and a 1–3 mm fraction of natural zeolite were used for the batch leaching test. 20 ml of solution (L_1) (adjusted to pH 4.0 with nitric acid) and 1 g of solid material in proportion corresponding to a liquid-to-solid ratio (L/S) = 20 l/kg ± 2% were shaken for 24 h and filtered through a 0.45 µm membrane syringe filter. The heavy metal mixture was analysed by Atomic Absorption Spectrophotometry (AAS, Buck Scientific's 210VGP).

A pilot test bench was constructed for the study the sorption of petroleum products by natural zeolite. 40 l of snowmelt water, 1 l of gasoline and 1 l of diesel were mixed and filtrated through a 20-cm layer of natural zeolite. A TOG / TPH analyser was used for the detection of petroleum product concentrations in filtrate samples. Individual samples were prepared using the Hexane extraction procedure.

RESULTS AND DISSCUSSION

The results of the previous experiments carried out with a natural sorbent, zeolite, could be used for improving the storm water runoff treatment system. The porevious experiments are described in detail elsewhere (Brannvall, Kazlauskiene, 2005; Mažeikienė et al., 2005; Anisimova et al., 2005; Brannvall, 2006; Brannvall et al., 2006; Baltrėnas, Brannvall, 2006). The results have shown that natural zeolite is suitable for heavy metal immobilisation in soil and of removal heavy metal and petroleum products from contaminated water.

For example, when four soil samples collected near the main highway connecting the biggest cities of Lithuania were separately contaminated with mixtures of Cu(II) nitrate, Pb(II) nitrate and Zn(II) nitrate dissolved in distilled water at three contamination levels (50 mg/kg, 100 mg/kg and 500 mg/kg of each metal), mixed with 5%, 10% and 20% of zeolites and left for one month, the sorption efficiency was highest when the content of natural zeolite in sandy soil was 20% (Fig. 2) (Brannvall, 2006). The lowest efficiency (16.1%) for Pb sorption from sandy soil

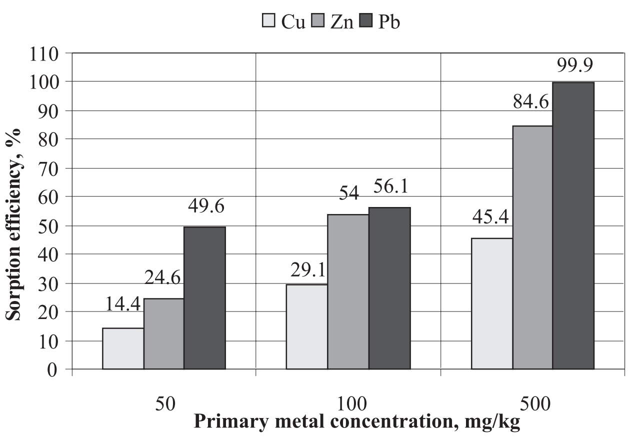

Fig. 2. Efficiency of heavy metal immobilization in sandy soil by 10% of natural zeolite
2 pav. Sunkiųjų metalų sulaikymo 10% gamtiniu ceolitu smėlio dirvožemyje efektyvumas

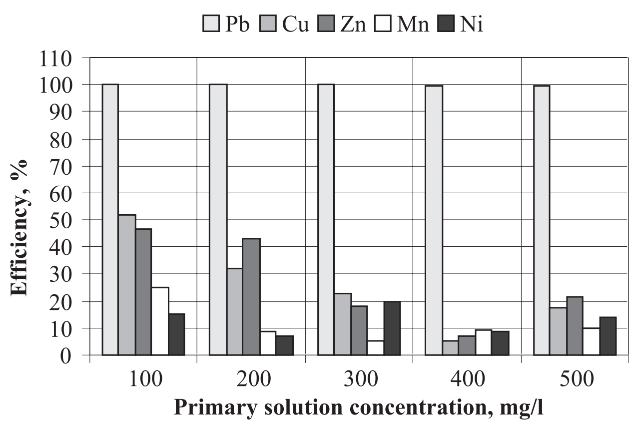

Fig. 3. Efficiency of heavy metal sorption by natural zeolite from metal mixture solution (batch leaching test), %
3 pav. Sunkiųjų metalų sorbcijos gamtiniu ceolitu iš metalų mišinio efektyvumas (%)

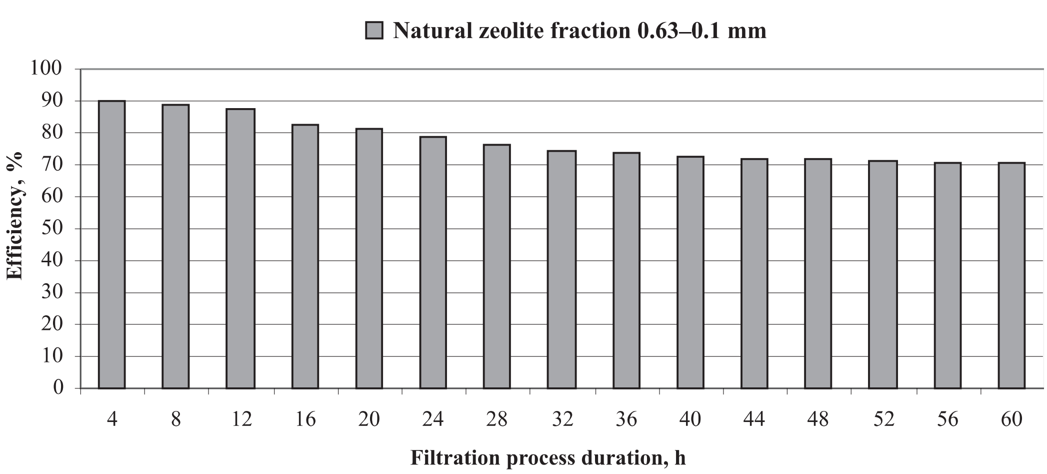

Fig. 4. Sorption efficiency of petroleum products by natural zeolite calculated from runoff-filter pilot test bench
4 pav. Naftos produktų sorbcijos gamtiniu ceolitu efektyvumas, apskaičiuotas remiantis lietaus nuotekų valymo filtro laboratoriniu eksperimentu

was shown by 5% of natural zeolite at the 100 mg/kg concentration level. The efficiency (99.9%) of Pb sorption was highest at the highest contamination level (500 mg/kg) and with 20% of natural zeolite in sandy soil. Zinc was adsorbed best (84.6%) at the highest contamination level and 20% of natural zeolite. The lowest efficiency of Zn immobilization in sandy soil was observed at the lowest contamination level and the lowest percentage of natural zeolite in sandy soil samples. Only 2% of Cu was adsorbed by 5% of natural zeolite at the lowest contamination level (50 mg/kg) of sandy soil samples. Pb was immobilized better than Zn and Cu. At the initial concentration of 500 mg/kg of heavy metals in sandy soil, 10% of natural zeolite was enough to immobilize Pb and Zn. The highest efficiency of Pb, Zn and Cu immobilization in sandy soil by natural zeolite was 99.9%, 84.6% and 45.4% respectively.

Five heavy metals, Pb, Cu, Zn, Mn and Ni, were chosen for the batch leaching test in order to define their sorption efficiency by natural zeolite. These metals are usually present in highway storm water runoff (Fig. 3). Heavy metal removal from the mixed metal solution showed good results for lead sorption by natural zeolite. Lead was sorbed best of all – 99.6% to 100% at different concentrations of the metal in the mixed solution of metals. When the concentration of copper was 100, 200, 300, 400 and 500 mg/l, the efficiency of natural zeolite sorption was 51.6, 32.0, 22.6, 5.0 and 17.6%, respectively. Zinc was sorbed less but still significantly – 46.8, 43.0, 18.0, 6.9 and 21.8%, respectively, from the initial concentrations of the metal in the solution. Manganese and nickel were sorbed worse (25.0, 9.0, 5.3, 9.6 and 9.7% of manganese and 15.4, 6.9, 20.0, 8.8 and 14.0% of nickel).

Sorption of petroleum products by natural zeolite showed that the highest treatment efficiency (89.8%) was reached with natural zeolite fraction 0.63–1.0 mm at the initial concentration of petroleum product 15 mg/l and the initial filtration rate V_o = 5 m/h (Fig. 4) (Brannvall et al., 2006). When the zeolite filter medium with a particle size of 1.0–3.0 mm was used, the highest petroleum product removal efficiency was 76.4%.

STORM WATER RUNOFF TREATMENT SYSTEM

In the unreconstructed parts of highways in Lithuania, rainfall water, depending on the natural conditions, is removed employing drainage ditches, chamfers or natural inclines of the relief. Sometimes storm water runoff is directed from the road surface to the closest descent of the relief without collecting it into a treatment system (Fig. 5).

When widening the roads, the problem of storm water runoff removal and collection is solved by installing drainage systems. A plastic corrugated pipe with a coconut splint filter is used for the longitudinal drainage. Above the pipe, geotextile is laid, which obstructs the part of the pollutants and preserves the drainage pipes from sand. Storm water runoff, collected by the incline of the relief made on one side of the road, flows into the drainage ditch. Storm water runoff outlets are installed every 50 meters; they direct the runoff straight into the drainage ditch. A check well is installed every 50 meters as well to maintain and clean the outlets if necessary.

To improve the removal of contaminants from storm water runoff, it is recommended to use the sorbtive layer of natural zeolite. Storm water runoff filtrates through a 0.2 m layer of zeolite and sand mixture (10% of zeolite in the sand volume) which sorbs the pollutants and the cleaned runoff is directed to the drainage ditch (Fig. 6). The infiltration-grassy-A-line type storm water runoff treatment system is chosen. Ditches with the flattened bottom are used in Lithuania. The treatment system is designed for a highway sector of 7 kilometers, because the reconstruction of a highway is usually performed on such lengths. However, the length of the sector can be chosen according to the relief conditions and the size of the runoff basin associated with the treatment system. The parameters of the ditch are as follows: width 1.0 m, depth 0.8 m, soil enriched with organic matter 0.1 m. Taking into account the present requirements to drainage ditches used in Lithuania, the improvement of the storm water runoff treatment system could be done with minimal changes.

Fig. 5. An example of storm water runoff directive system on the Vilnius–Klaipėda highway (Lithuania)
5 pav. Lietaus nuotekų nukrepiančioji sistema kelyje Vilnius–Klaipėda (Lietuva)

The efficiency of the improved infiltration-grassy-A-line type storm water runoff treatment system depends on the runoff contamination level, groundwater level, soil type, etc. This storm water runoff treatment system should be located in an ordinary roadside drainage ditch with regard to the conditions of precipitation flow from the surface of the carriageway. The location should be chosen depending on the carriageway and roadside levels as well as on the possibility to direct storm water flow into the outward reservoirs.

The main advantages of the improved infiltration-grassy-A-line type storm water runoff treatment system are an efficient pollutant removal from the storm water runoff, the low cost of the sorbent, natural zeolite, which is environmentally friendly and shows a very high sorption capacity. This material can be used for a long time without changing it.

CONCLUSIONS

1. The observed order of metal sorption by natural zeolite was as follows: $Pb^{2+} > Zn^{2+} > Cu^{2+}$. When their concentration in soil was 500 mg/kg and the content of natural zeolite was 10%, 92% of Pb, 56% of Zn and 40% of Cu were sorbed by natural zeolite.

2. Calculating the efficiency of metal reduction and the costs of the additive, the content of zeolite in soil should be 10%, if the contamination level with heavy metals of soil does not exceed 500 mg/kg.

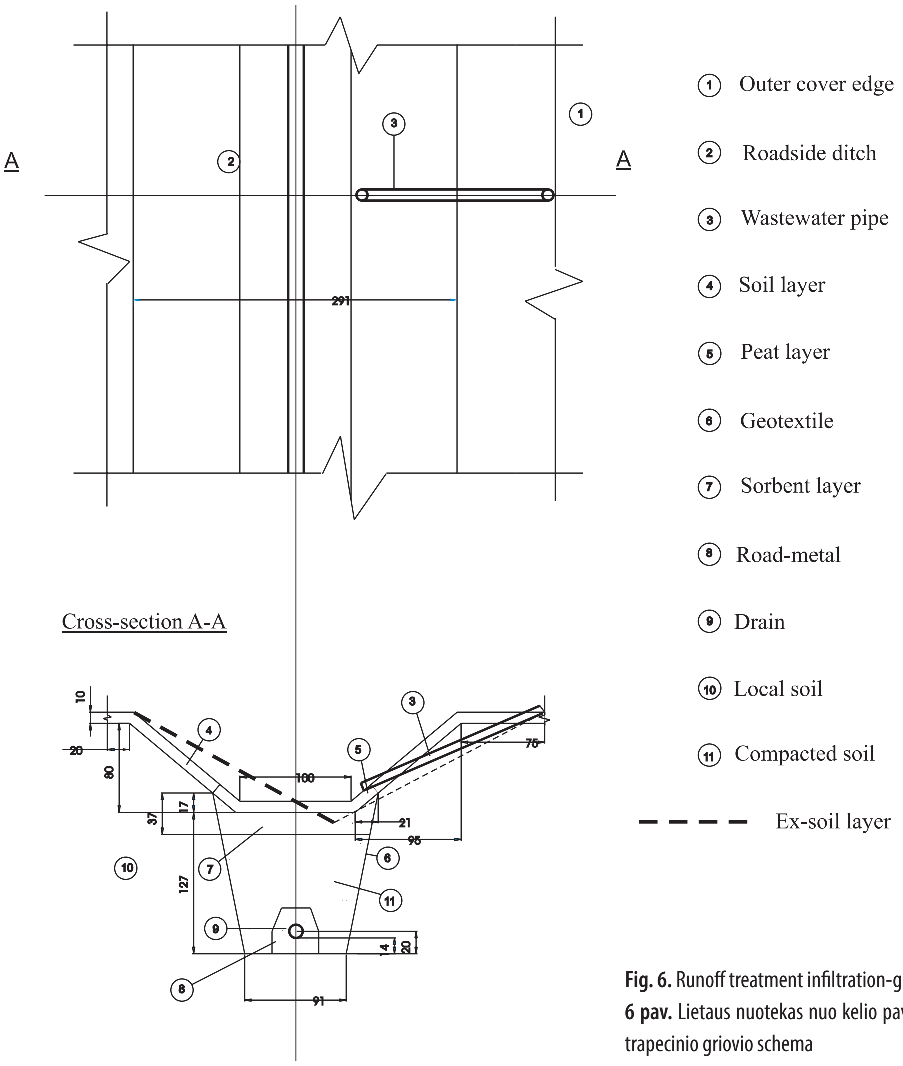

Fig. 6. Runoff treatment infiltration-grassy-A-line type system with natural zeolite layer
6 pav. Lietaus nuotekas nuo kelio paviršiaus surenkančio ir valančio infiltracinio-žolinio-trapecinio griovio schema

3. Heavy metal sorption by natural zeolite from mixed metal solutions has shown that Pb is sorbed the best (100%), followed by copper (52%), zinc (47%), manganese (25%) and nickel (15%) at the initial concentration of 100 mg/l of metals in the solution.

4. The removal efficiency of petroleum products by two fractions (0.63–1.0 mm and 1.0–3.0 mm) of natural zeolite from water was 89.8% and 76.4%, respectively at the initial concentration of petroleum products 15 mg/l.

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Evelina Brannvall

NUOTEKŲ VALYMO SISTEMOS SU GAMTINIU MINERALINIU SORBENTU TOBULINIMAS

S a n t r a u k a

Lietaus ir sniego tirpsmo vanduo, nuplaudamas nuo kelio paviršiaus naftos produktus ir kitus teršalus, suteka į pakelės griovius. Lietuvoje šie grioviai nėra tinkamai apsaugoti, kad užterštos nuotekos nepatektų į požeminius vandenis. Pakelės griovių nuotekų surinkimo sistemos yra techniškai bei moraliai pasenusios, todėl į paviršinius vandenis suteka ne itin išvalytos nuotekos. Patobulintos lietaus nuotekų valymo sistemos esmė yra sorbuojantis 0,2 m smėlio ir 10% gamtinio ceolito mišinio sluoksnis. Nuotekų valymo grioviai yra apauginti žolėmis. Infiltracinio-žolinio-trapecinio nuotekų valymo griovio su gamtinio ceolito ir smėlio mišiniu efektyvumas yra maždaug 10% didesnis negu paprasto, tik su smėlio sluoksniu, lietaus nuotekų valymo įrenginio. Rekomenduojama naudoti patobulintą infiltracinį-žolinį-trapecinį lietaus nuotekas nuo kelio paviršiaus surenkantį griovį.

Эвелина Браннвалл

УСОВЕРШЕНСТВОВАНИЕ СИСТЕМЫ ОБРАБОТКИ СТОКА ДОЖДЕВОЙ ВОДЫ ЕСТЕСТВЕННЫМ МИНЕРАЛЬНЫМ СОРБЕНТОМ

Р е з ю м е

Дождевая и талая вода, загрязненная нефтепродуктами, тяжелыми металлами и другими загрязнителями, попадает в придорожные водоотводные канавы. В Литве такие каналы нефункциональны: они не защищают грунтовые воды от различных загрязнителей.

Имеющиеся системы обработки стока дождевой воды технически и морально устарели, в результате чего в поверхностную воду попадает загрязненная вода. Улучшить системы обработки стока дождевой воды предлагается сорбционным слоем толщиной 0,2 м из смеси песка и 10% естественного цеолита. Растущая над такими системами трава в качестве инфильтрата повышает эффективность системы примерно на 10%. Рекомендуется использовать улучшенную систему обработки стока дождевой воды со смесью песка и 10% естественного цеолита.