Desalination and Water Treatment
www.deswater.com

1944-3994/1944-3986
doi: 10.1080/19443994.2012.695039

51 (2013) 1543–1548
February

Taylor & Francis
Taylor & Francis Group

The performance of a fixed-bed treatment system packed with layered textiles for their filtration/adsorption potential for salt and organic pollutant

Alenka Ojstršek*, Darinka Fakin

Faculty of Mechanical Engineering, Department for Textile Materials and Design, University of Maribor, Smetanova 17, Maribor 2000, Slovenia
Email: alenka.ojstrsek@uni-mb.si

Received 21 February 2012; Accepted 10 May 2012

ABSTRACT

The main contribution of the research work presented here was to select and investigate a few commercially available textiles to study their filtration/adsorption potential for salt and total organic carbon (TOC) reduction during wastewater treatment. First, several physical–mechanical properties, such as tensile strength, thickness, weight, density and structural aspect of two woven (polyamide and polyester) and two nonwoven (polypropylene [PP] and PP/polyethylene [PE]) textiles, were determined. Also, the void amount and total void area percentage of textiles were measured, which influence the wastewater flow (clog) and filtration efficiency. With the intention of examining the adsorption ability of the selected textiles, kinetic experiments were carried out in shake-flasks using three commonly-used salts. Afterwards, small-scale column experiments were conducted in a continuous-flow operation to assess the TOC and salt reduction. It was found that both nonwoven textiles (either made from PP or from bicomponent PP/PE) with the more complex structures and a higher total void area were more suitable for the removal of salt and TOC in comparison to the efficiency of a column packed with sand/woven fabrics, regarding the type and concentration of salt as well as the contact time.

Keywords: Compact textiles; Fixed-bed system; Salt reduction; TOC reduction; Ecology

1. Introduction

Recently, there has been a great deal of research aimed at resolving environmental problems caused by hazardous wastewaters being discharged from various sources including different industries, hospitals, households, etc. [1]. Several processes are being introduced, among which bioremediation is increasingly being seen as a socially acceptable solution. Bioremediation is the preferred choice on account of its expanded environmental sensitiveness and its convenience to cater to even small communities as well as to be applied for tertiary treatment in larger city systems. In fixed-bed treatment systems, the microbial biomass is static—immobilized to the bedding (support) material, while the treated fluid is mobile—it flows through several engineered biological systems, i.e. biofilters, rotating biological contactors, reactors with fluidized beds, membrane bioreactors, activate sludge systems, etc. [2]. As an alternative to

*Corresponding author.

Presented at the International Conference on Desalination for the Environment, Clean Water and Energy, European Desalination Society, 23–26 April 2012, Barcelona, Spain

the high-cost bedding materials or porous membranes and its high-energy demands, low-cost and easily-available filter media such as nonwoven textiles, fibres, mesh and filter cloth, are extensively researched for the above-mentioned treatment systems [3]. The reported results have demonstrated that fibrous materials themselves or in combination with sand, gravel, zeolite, etc., are exceedingly effective in the removing of organic and solid pollutants, nutrients, metal species, etc., from domestic or industrial wastewaters at different operating conditions [4–10].

Although the filtration/adsorption of pollutants from wastewater is a function of different external factors, such as characteristics of the pollutant (dissolving, molecule size, ionization and polarity), characteristics of water system (temperature, pH, total suspended solids), etc., it is very important to select such textile materials that would have an appropriate chemical structure, physical–mechanical properties (breaking strength, thickness, mass, flexibility, surface charge, pore size, etc.), sufficient permeability (also after long-term operation) and resistance to biological degradation, mechanical usage and several pollutants' activity [11,12]. The filtration functions of textiles can fail either by virtue of microorganisms multiplying on surfaces or by chemical precipitation from mineral substances blocking the pores.

The most commonly applied fibre-forming polymers in hazardous waste plants are predominantly made from polypropylene (PP), polyamide (PA) and polyethylene (PE), whilst polyester (polyethylene terephthalate or polybutylene terephthalate) is almost inevitably used when the higher strengths are required [5,11]. Textiles made from these polymers are basically designed from three types of yarns, namely monofilament, multifilament and staple-fibre yarns, and are generally non-woven, heat-bonded or needle-punched and woven textiles.

Hence, the aim of this study was to evaluate the adsorption/filtration possibility of four commercially available compact textiles for salt and organic pollutant removal in fixed-bed systems in comparison to the sand substratum. Thus, a series of shake-flask experiments were conducted as well as the column trials to examine the wastewater treatment efficiency of selected textiles. Preliminary, some physical–mechanical properties of textiles were determined as well as the resistance of textiles to biological degradation.

2. Experimental

2.1. Textiles and chemicals

Four structurally different compact textiles were employed in the presented research, i.e. two woven fabrics made from PA and polyester (PES) fibres, respectively, and two non-woven heat-bonded textiles made from 100% PP yarn (30% Trevos and 70% Danaklon, 2.2 dtex) and bicomponent PP/PE core-shell yarn (Danaklon ES-C, 2.2 dtex). All textiles were bleached, but were not subjected to any other finishing procedures.

All chemicals applied were of analytical grade: sodium hydroxide (NaOH), sodium sulphate $Na_2SO_4 \cdot 10H_2O$ and urea were purchased from Fluka and sodium chloride (NaCl) from Merck.

2.2. Adsorption experiment

The adsorption capability of the selected textiles was accomplished by kinetic experiments using a series of shake flasks. The solutions were prepared by dissolving three widely used salts, i.e. NaCl, urea and $Na_2SO_4 \cdot 10H_2O$, respectively, in 100 mL of deionized water with initial concentrations of 6, 12, 18 and 24 g/L. The flasks were sealed and shaken on an orbital shaker with 160 rpm for 24 h at 22°C. Afterwards, the fabrics were taken out from the flasks; dried and weighted. The amount of adsorbed salts was calculated as the differences in fabrics' weight after and prior to the trials started.

2.3. Fixed-bed experimental set-up

The experimental set-up was composed of a polypropylene column with a diameter of 6 cm and a length of 36 cm (1 L volume), with inlet and outlet pipes, a plastic reservoir for the wastewater storage equipped with a stirrer for constant mixing, a pump to attain a continuous wastewater flow through the filled column (approximately 30 mL/h) and a settler for the excess biomass. The columns were fortified with a PP net and separately packed with: (a) washed sand received from a quarry in Slovenia (control column) with a particle size of 2–12 mm with a bed height of 28.5 cm, packed weight of 625 g and bed porosity of 0.36, and (b) alternating strata of washed sand (with properties as in a control column) and layers of individual compact textile to establish the textiles to behave as filters, and thus, reduce the salt, and organic pollutants from synthetically prepared wastewaters. Samples for the analysis were collected from the outflow once a day, during 40 days of trial period, with the exception of Saturdays and Sundays, and thereafter directly analysed. All experiments were performed at an ambient temperature of 22 ± 2°C.

The case study's experiment was carried out on a synthetically prepared wastewater containing 0.5 g/L of a sequestering agent Alvirol AGK (Textilcolor) and

0.5 g/L of an anionic wetting and de-aerating agent Cibaflow PAD (Ciba) to reach organic pollution, and 2 g/L NaCl, 2 g/L $Na_2SO_4 \cdot 10H_2O$ and 2 g/L urea for attaining the wastewater salinity as well as NaOH for regulating the wastewater alkalinity (pH 9–10), simulating the effluents from textile effluents. Alvirol AGK is a chemical mixture of polyacrylates and oxycarbonic acids. The Cibaflow PAD is chemically based on an alkylphosphate and fatty alcohol ethoxylate.

2.4. Analytical methods

Some mechanical properties, i.e. elongation at break, tensile strength and breaking tenacity of applied textiles, were measured according to the standard DIN 53857 using the Textechno statigraph M test machine. Also, some other physical-mechanical properties were determined such as thickness, weight and density by standardized methods.

In addition, several field parameters, i.e. the total void area, total void area percentage, total void parameter and number of voids per mm^2, which have an influence on textiles' permeability and adsorption ability as well as on the eventual clog of the pores, were measured by the microscopic method using an Axiotech 25 HD (+pol) microscope (Zeiss), equipped with an AxioCam MRc (D) high-resolution camera and KS 300 Re. 3.0 image-analysis software. The cover factor (CF) in percentage was calculated as the difference between 100% and total void area %. A total of 20 measurements were obtained from each sample and then statistically evaluated. The details of procedure were described elsewhere [13].

The microbiological resistance of selected fibre-forming materials and consecutively, their adequacy for application in biological processes was determined by burying textile samples (7 cm^2) into soil with the following characteristics: N 1.2–1.7%, P 0.8–1.2% and K 0.7–1.2%, organic compounds 20–25% and pH 7.7–8, according to standard EN 12225:2001 in a climatic chamber KK-105 CH (Kambič). Biodegradability was calculated as the differences in the fabrics' weight of initial and washed/dried samples that were buried approximately 6 months divided by the weight of initial sample in percentages.

The fixed-bed experiments' performance was evaluated by monitoring the total organic carbon (TOC) and electrical conductivity (EC) in synthetically prepared wastewaters prior to and after the column tests. The total organic carbon (TOC) was measured by means of a DC-190 Analyzer (Dohrmann), in accordance with the ISO 8245 standard and the electrical conductivity was determined using MultilabP5 (WTW).

3. Results and discussion

3.1. Characterization of employed textiles

In this case study, four commercially accessible textiles were applied (two woven and two nonwoven, respectively), made from the most commonly used fibrous materials for wastewater purification. The results of determined physical–mechanical properties and structural parameters of selected four textiles that influence on textiles stability in fixed-bed treatment systems are gathered in Table 1.

It is evident from Table 1 that both the woven fabrics have superior tensile strength, breaking tenacity and elongation at break compared to both the nonwovens.

Microorganisms in soils had a negligible influence on the used textiles' degradation, thus this feature could be applied in biological treatment systems, with the exception of non-woven PP/PE fabric with a weight loss of 26.17%.

The surface characteristics of used textiles have the greatest influence on their adsorption/filtration ability in treatment systems; therefore, the total void area, the number of voids and the total void parameter were measured using a microscope equipped with a high-resolution camera and an image-analysis software. The measurements were carried out in accordance with a pre-defined macro, thus ensuring that all the samples were analyzed in the same way and under the same conditions. The obtained results are gathered in Table 2. Fig. 1 shows the textiles' microscopic photographs.

Table 2 shows the results of measured field parameters. Both nonwoven textiles have a similar surface characteristic with a higher total void area and the number of voids/mm^2 in comparison with both the woven fabrics, as could also be perceived from Fig. 1. Therefore, they are more suitable for filtration purposes as both woven fabrics, which was also proven by the adsorption and fixed-bed treatment experiments. Generally, a nonwoven material is composed of a random network of overlap fibres creating multiple connected pores through which the fluid can flow [14]. However, if the size of the textiles' pore is smaller than that of the particle, then the particle will be deposited on the material surface forming a cake layer and consecutively, causing a fouling of textiles.

3.2. Adsorption ability

For the adsorption trials, three commonly used salts were employed in four concentrations, 6, 12, 18 and 24 g/L. The contact time was 24 h. The amounts of

Table 1
Some physical–mechanical characteristics and biodegradability of employed textiles

Properties	PA woven	PES woven	PP non-woven	Bico PP/PE non-woven
Elongation at break (%)	76.7	49.9	40.9	9.7
Tensile strength (N)	975	1,261	43	60.3
Breaking tenacity (cN/tex)	487.7	630.7	132	77.2
Thickness (mm)	0.39	0.49	0.22	0.23
Weight (g/m^2)	111	160	20	22
Density (threads/10 cm)				
Warp	450	220	/	/
Weft	230	200		
Weave	Twill	Plain	/	/
Biodegradability (%)	1.13	0.03	0.06	26.17

Table 2
Field factors of used textiles (mean value of 20 measurements)

Field parameters	PA woven	PES woven	PP non-woven	Bico PP/PE non-woven
Total void area (%)	0.08	0.98	15.74	15.36
Total void area (mm^2)	0.03	0.22	2.29	2.46
Number of voids (mm^2)	11.17	10.47	440.43	413.38
Total void parameter (mm)	2.83	8.93	189.33	177.15
Cover factor (%)	99.92	99.02	84.26	84.64

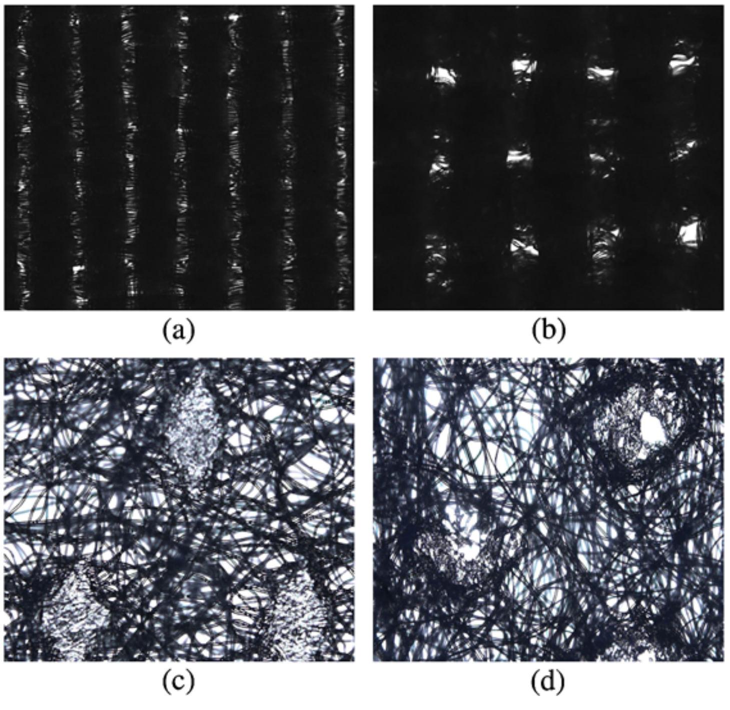

Fig. 1. Microscopic images of surface voids of (a) PA, (b) PES, (c) PP and (d) bicomponent PP/PE; enlarged five times.

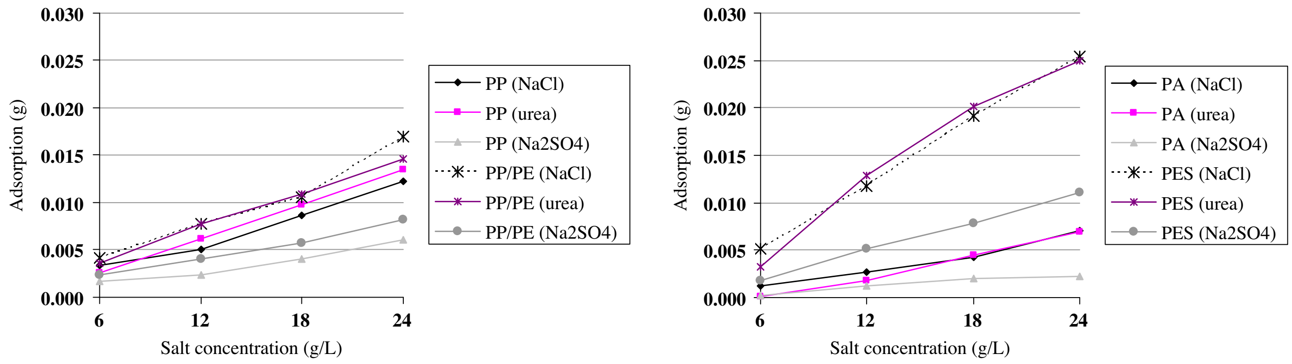

Fig. 2. The amount of adsorbed salt on nonwoven textiles (left) and woven textiles (right).

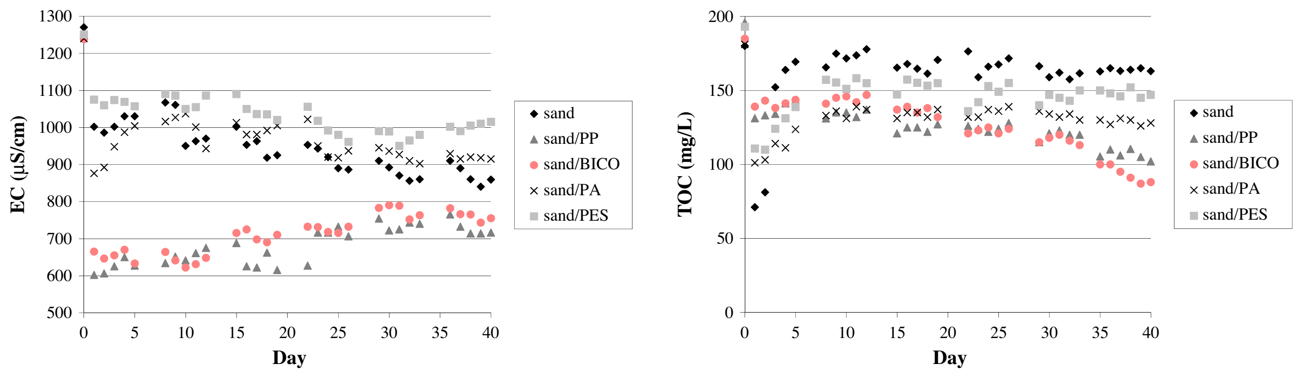

Fig. 3. Electrical conductivity (left) and TOC (right) in initial and treated wastewater.

adsorbed salts were expressed as the differences in fabrics' dry weight after and prior to the trials started in grams vs. the concentration of applied salt, and the results are shown in Fig. 2.

The proportion of adsorbed NaCl and urea on the sample surface was higher in the case of nonwoven textiles, with the exception of a woven PES fabric (Fig. 2—right diagram). Generally, it could be concluded that the fabric construction had a superior impact on the adsorption ability ahead of the salt type. The adsorption degree increases almost linearly increasing the salt concentration.

3.3. Salt and TOC reduction in a fixed-bed system

The electrical conductivity (EC) that depended on the salt content and TOC was monitored in initial and treated wastewater for 40 days of treatment period in a fixed-bed system packed with alternating layers of sand/textiles as compared with the control column sand filled. The system was operated continuously without backwashing at a velocity flow of approximately 30 mL/h and a retention time of 12–14 h. The obtained results are gathered in Fig. 3.

It is evident from Fig. 3 that EC importantly decreased only during the treatment in a system filled with sand/nonwoven textiles, from 185 µS/cm down to 88 µS/cm (bico PP/PE) and from 196 µS/cm down to 102 µS/cm (PP), as could also be implied from the preliminary adsorption shake-flask experiments. Furthermore, the best TOC removal on the last day of the experiment was detected in the wastewater that flowed through the column packed with a combination of sand and bicomponent PP/PE yarn, i.e. for 52.4% (from 185 mg/L down to 88 mg/L); followed by a 48% reduction in the wastewater that flowed through the column combined of sand/PP textiles (from 196 mg/L down to 102 mg/L). In the trial when only sand was employed, the TOC values decreased the least, from 180 mg/L down to 163 mg/L (for 9.4%). Ultimately, the well-formed fibre pores of the textiles (preferably nonwovens as shown in Fig. 1) could be grown with various microorganisms' populations after a prolonged period of system function, due to the low velocity-flow and long retention times. Colonization of the column material by microorganisms provides a passive uptake of auxiliaries in a manner of surface adsorption, complex formation, ion exchange and microprecipitation.

4. Conclusions

During the presented case study, the possibility of using various commercially available textiles for salt and TOC reduction during fixed-bed wastewater treatment was investigated. From the results obtained by the samples' surface analyses, field parameter measurements (microscopic method) as well as from the adsorption experiments, it could be concluded that a better degree of salt adsorption was attained using both nonwoven textiles (PP and bicomponent PP/PE) ahead of both woven fabrics (PA and PES) regarding the type of salt and its concentration. The maximal TOC reduction by up to 52% was also reached using a combination of sand and nonvowen bicomponent textile. Generally, the fabrics' surface texture, preferably, total void area and number of voids per mm, had a crucial role on salt and TOC removal efficiency, influencing the textiles' solid filtration, adsorption, ion exchange and even microorganisms' growth ability.

Acknowledgement

This basic research was sponsored by the Slovenian Research Agency, Project No. Z2-2064.

References

[1] T. Griessler Bulc, A. Ojstršek, The use of constructed wetland for dye-rich textile wastewater treatment, J. Hazardous Mater. 155 (2008) 76–82.

[2] V.L. Barbosa, R. Tandlich, J.E. Burgess, Bioremediation of trace organic compounds found in precious metals refineries' wastewaters: A review of potential options, Chemosphere 68 (2007) 1195–1203.

[3] S.H. Chuang, W.C. Chang, M.C. Chang, K.L. Hu, Filtration performance of a novel submerged nonwoven filter for particle separation, Desalination 279 (2011) 163–169.

[4] S.M. Ibrahim, Removal of copper and chromium ions from aqueous solutions using hydrophilic finished textile fabrics, Fibres Textiles Eastern Europe 18 (2010) 99–104.

[5] M.B. Mendonça, M.C. Cammarota, D.D.C. Freire, M. Ehrlich, A new procedure for treatment of oily slurry using geotextile filters, J. Hazard. Mater. 110 (2004) 113–118.

[6] C. Yaman, J.P. Martin, M. Asce, E. Korkut, Use of layered geotextiles to provide a substrate for biomass development in treatment of septic tank effluent prior to ground infiltration, J. Environ. Eng. 131 (2005) 1667–1675.

[7] J.D. Ortego, T.M. Aminabhavi, S.F. Harlapur, R.H. Balundgi, A review of polymeric geosynthetics used in hazardous waste facilities, J. Hazard. Mater. 42 (1995) 115–156.

[8] G.T. Seo, B.H. Moon, T.S. Lee, T.J. Lim, I.S. Kim, Non-woven fabric filter separation activated sludge reactor for domestic wastewater reclamation, Water Sci. Technol. 47 (2003) 133–138.

[9] X. Ren, H.K. Shon, N. Jang, Y.G. Lee, M. Bae, J. Lee, K. Cho, I.S. Kim, Novel membrane bioreactor (MBR) coupled with a nonwoven fabric filter for household wastewater treatment, Water Res. 44 (2010) 751–760.

[10] W.K. Chang, A.Y.J. Hu, R.Y. Horng, W.Y. Tzou, Membrane bioreactor with nonvoven fabrics as solid–liquid separation media for wastewater treatment, Desalination 202 (2007) 122–128.

[11] A.R. Horrocks, S.C. Anand, Handbook of Technical Textiles, Woodhead Publishing Limited, Cambridge, 2000.

[12] A.H. Aydilek, T.B. Edil, Filtration performance of woven geotextiles with wastewater treatment sludge, Geos. Intern. 1 (2002) 41–69.

[13] M. Gorenšek, R. Urbas, S. Strnad, Đ. Parac-Osterman, The evaluation of a natural pigment in cotton as a UV absorber, AATCC Rev. 7 (2007) 50–55.

[14] M.C. Chang, R.Y. Horng, H. Shao, Y.J. Hu, Performance and filtration characteristics of non-woven membranes used in a submerged membrane bioreactor for synthetic wastewater treatment, Desalination 191 (2006) 8–15.