Journal of Water Process Engineering 5 (2015) 118–126

Contents lists available at ScienceDirect

Journal of Water Process Engineering

journal homepage: www.elsevier.com/locate/jwpe

Water quality produced by polystyrene granules as a media filter on rapid filters

Juliana M. Schöntag*, Bruno S. Pizzolatti, Victor H. Jangada, Fernando H. de Souza, Maurício L. Sens

Universidade Federal de Santa Catarina, Graduate Program in Environmental Engineering, Campus Universitário UFSC/CTC Florianópolis – Santa Catarina, 88040-900, Brazil

ARTICLE INFO

Article history:
Received 15 May 2014
Received in revised form 14 January 2015
Accepted 1 February 2015
Available online 9 February 2015

Keywords:
Rapid filter
Backwashing
Polystyrene granules
Water quality

ABSTRACT

Many devices are used to improve the performance of rapid filters, increasing the filter run and reducing the velocity of the wash water filter with the use of multiple layers and the adoption of different filter materials. This study constructed a descending rapid filter utilizing polystyrene granules as a new filter element; this was compared to a sand and anthracite descending rapid filter. The filter performance was compared in terms of water quality, turbidity, apparent and true color, conductivity, total dissolved solids, temperature, pH, residual aluminum, and removal of cyanobacterium (*Cylindrospermopsis raciborski*) under the same operating conditions of filtration. The sand and anthracite filter reached the greatest filtration run, but the water quality of the polystyrene filter had a similar quality to the sand and anthracite filter. Furthermore, the filter containing polystyrene granules as a media filter can represent savings with decreased wash water and the construction of reservoirs with a lower hydraulic load.

1. Introduction

The filtration process is essential in the treatment of potable water. It is an important step for particle removal, the latter retained in the media filter [3,20]. The sand, or a combination of sand and anthracite (double layer), is widely used as a media filter. However, different materials may be used in order to improve the performance of the filters. Materials with different densities are typically used with the aim of increasing the filtration runs. Knudsen [11] established relationships between different grain sizes and distinct masses of materials commonly used in descending rapid filtration (sand, anthracite and garnet), but backwashing was not addressed.

During the filter cleaning process, the backwash rate must be large enough to wash (remove) the material captured by the bed, but not so high that the filter material is pushed out of the filter (loss). To prevent loss of the filter material, it is necessary to determine the bed expansion that occurs with the fluidized material.

Akgiray and Saatçi [1] showed that the Ergun equation is valid for fixed and expanded beds. However, in a fluidized bed, the head loss becomes constant. The head loss of the filter material can be measured and/or evaluated by testing the expansion of the material and depends on the characteristics of the material.

Some authors have used alternative materials with different densities in order to improve the performance of the filters, such as [8,18], who used pumice as a filter element. Other authors have used polymers with the same purpose, such as [13], who used this material in wastewater treatment. In 2008, Fabris et al. [7] reported on the water treatment plant (WTP) in Skullerud, Norway. This WTP (water treatment plant) applies the technology of direct descending filtration whose filters have a triple layer filter, including two layers of different plastic (each a polyethylene compound and various chalk additives) and a layer of sand. According to reports from Marie Fossum (personal contact), the chief engineer of the water department in Oslo, the station worked well for many years and the water quality was satisfactory. However, the capacity of the filter has deteriorated in recent years. They are working on a project to improve the capacity and replace the filter material with the same material or use other materials as filter elements, with characteristics similar to what is currently used. However, none of these authors mention the use of these filter elements with different densities in order to increase the cleaning efficiency and/or increase the effective water production.

The polymeric material has shown to be favorable because it is commercially available, it is lightweight and the granules have many geometric forms.

* Corresponding author. Tel.: +55 48 3721 9883.
E-mail address: juschontag@gmail.com (J.M. Schöntag).

http://dx.doi.org/10.1016/j.jwpe.2015.02.001
2214-7144/

The inconvenience of performing a conventional washing with a granular media filter is that the increase in water velocity is excessively high, from 0.02 to 0.4 m/s. Only at high velocities does it reach the optimal porosity for particle detachment [2]. In addition to the particle detachment, the backwash speed is directly related to the particles being drawn out of the filter during backwashing.

The use of a material with low density, such as polystyrene granules, could produce a water quality equivalent to a conventional dual layer sand and anthracite filter and at the same time reduce the high water velocity used during backwashing, since it is a lightweight material of 1046 kg/m^3.

With optimal speed, it is possible to detach the particles which have adhered to the grains and drag them to the exit point of the wash water without losing material. The velocity range would be lower than the conventional range, and there would be an economization of wash water and higher effective production.

The polystyrene granules have proven to be appropriate and some authors have already worked with this material. Hsu et al. [10] tested a semi-empirical approach for predicting collision efficiencies of giardia cysts and cryptosporidium oocysts for the colloid deposition in both 2 mm glass beads and 2 mm polystyrene bead filters. By adjusting the electrolyte concentrations, the variation in removal efficiencies and experimental collision efficiencies of both parasites by the glass beads can be less significant than that for the polystyrene beads. However, the opposite results for glass beads versus polystyrene beads were obtained by adjusting the pH values. Šećerov Sokolović et al. [17] observed that the use of EPS as a filter medium drastically decreases both capital and operating costs and offers great possibilities for filtration optimization. Harwanto et al. [9] observed the removal efficiencies of total ammonia nitrogen (TAN) of a sand filter (SF), polystyrene micro bead filter (PF), and Kaldnes bead filter (KF) under different ammonia loading rates. TAN removal rate increased with an increasing ammonia loading rate for all filter media. Mean volumetric TAN removal rates for these ammonia loading rates in SF were higher than those in PF and KF. These results were related to differences in the specific surface areas of the filter media. PF was the most economic media for efficiently removing TAN. In accordance with Schöntag and Sens [16] the polystyrene granule can be used as a granular media filter with the right care taken at the time of backwashing.

To contribute to the production of drinking water, this study was conducted to introduce a new type of filter element, the polystyrene granules, with the prospect of producing water quality similar to a conventional sand and anthracite filter, but with a possible reduction in the volume of backwash water. Furthermore, such a new filter element would allow savings in the construction of reservoirs with smaller dimensions due to lower pressure loss, and facilitate the use of pumps in back-washing.

2. Materials and methods

2.1. Filtration systems

A new filter element, polystyrene granules, was chosen to create a filter. The material is polystyrene, styrene polymer or crystal polystyrene. Its chemical composition is (C8H8) n. The expandable polystyrene is the raw material for the production of "styrofoam". The expanding agent is usually pentane gas, and this corresponds to approximately 3% of the material volume. This material is expanded when subjected to high steam temperatures, increasing its size by up to 50 times.

The producers of this product in Brazil are the Innova Petrochemical and Videolar companies. Its characteristics were obtained and it was found that it can be used as a filter element in descending rapid filters [16]. The technology employed was a direct filtration treatment (coagulation/filtration). Thus, two filters were constructed: A filter using expandable polystyrene (PS) as a media filter and a double layer filter of sand and anthracite (S + A). The characteristics of the filter elements are shown in Table 1.

Table 1
A comparison among the characteristics of polystyrene granules, sand and anthracite (averaged).

Characteristics	Polystyrene granules	Sand	Anthracite
Minimum size	0.50 mm	0.4 mm	0.6 mm
Maximum size	1.20 mm	2 mm	2 mm
Effective size	0.66 mm	0.62 mm	0.85 mm
Uniformity coefficient	1.36	1.69	1.65
Media grain diameter	0.87 mm	1.38 mm	0.95 mm
Porosity	0.387	0.550	0.665
Density	1.046 g/cm^3	2.610 g/cm^3	1.350 g/cm^3

The filters were constructed from stainless steel with a square cross section of 20 cm (Fig. 1). The polystyrene granules filter (specific diameter 0.68 mm) has a thickness of 97 cm.

The double layer filter has a sand layer with a thickness of 30 cm (specific diameter of 0.62 mm) and an anthracite layer with a thickness of 80 cm (specific diameter of 0.85 mm). The L/d (height of media/diameter of a particular grain) ratio is a trade-off between filtration efficiency and filter head loss. It is recommended that this relationship is between 1000 and 2000 [4]. It was established that this relationship was approximately 1426. The support layer is the same for both filters, with a particle size ranging from 1.18 to 19 mm.

The rate of the operation was 208 m^3/m^2 d (constant) with a variable hydraulic load. The raw water source, Peri Lagoon (Santa Catarina, Brazil), enters the reservoir and is driven to the rapid mixing unit, which receives the coagulant PAC (poly aluminum chloride) in a dose of 1.08 mg Al^{+3}/L. The velocity gradient of the rapid mixing chamber was 1200 s^{-1}. These parameters were defined in bench tests (jar-tests). After coagulation, the water was directed to a descending filter. The filters worked simultaneously.

2.2. Raw water quality

For this study, the source of the raw water supply was Peri Lagoon. Peri Lagoon is located in the south of the Brazilian island of Florianopolis and supplies the southeast regions of the island. The Peri Lagoon water treatment plant (WTP) was built with direct filtration technology with a double layer of anthracite and sand. This design, according to Dalsasso and Sen [5] is compatible with the parameters of the turbidity and true color of the lagoon, which are less than 10 NTU and 20HU, respectively. However, according to the authors, a year after starting the WTP operation, the increase of the concentration of phytoplankton was discovered. The species of domain is *Cylindrospermopsis raciborski* and *Pseudo anabaena* sp which had jumped in successive occurrences from 10,000 ind/mL or less to 250,000 ind/mL. In the case of Peri Lagoon, the WTP working with direct filtration without pre-treatment may cause the operation to be costly (fewer filter runs).

Other authors have proposed alternatives in order to "try" to solve this problem. Mondardo [12] proposed the dilution of Peri Lagoon waters, with water obtained through bank filtration technology, at a rate of 85% (filtered by bank filter), plus 15% (raw water pond). Mondardo [12] found that the bank filter removes 100% of phytoplankton in the water. When the raw water is diluted, there is a reduction of phytoplankton, which means a reduction of particles. Therefore, operating costs of direct filtration are lowered. Romero et al. [14] have shown a removal of 100% cyanobacteria and cianotoximas of Peri Lagoon water.

Although the characteristics of the proposed water source are not suitable for direct filtration, it was very useful in this study as

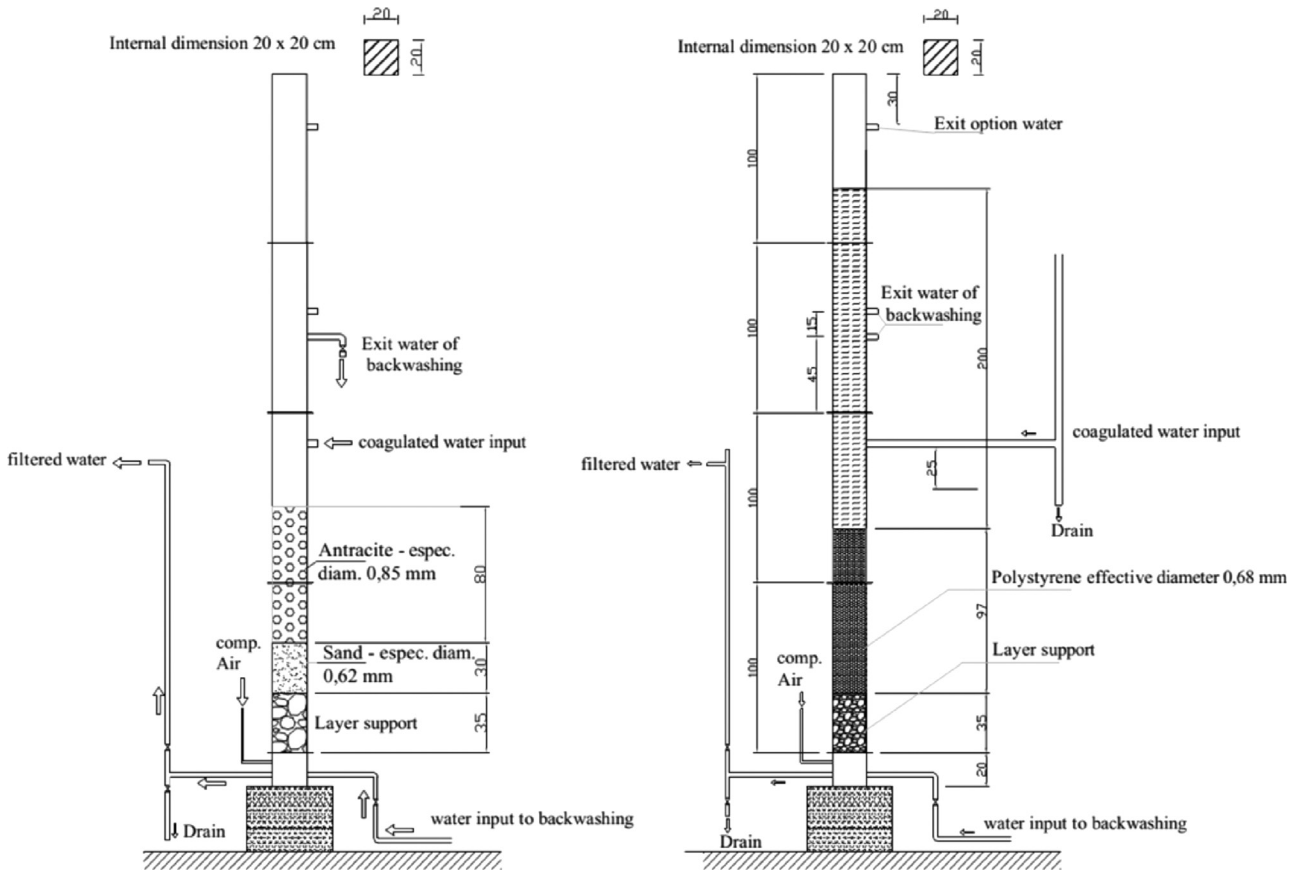

Fig. 1. Installation diagram of the pilot filters.

Table 2
The analyzed parameters of water quality and the equipment used.

Parameters	Equipment	Methods
Conductivity (μS/cm)	Portable conductivity meter HACH–Model HQ40D	Standad methods
Cyanobacteria count (*C. raciborski*) (ind/mL) (samples collected in the beginning of career and with 1 and 2 meter load)	Counting Chamber Sedgewick Rafter Cell S50- Microscope BX 40	(AZEVEDO, MARIA TERESA DE P.SANT'ANNA, 2006)
Apparent color (uH)	Spectrophotometer HACH DR/2010	Standard methods
True color (uH)	Filtration in a paper filter 0.45 μm–Spectrophotometer reading HACH DR/2010	Standard methods
pH	pH meter HACH	Standard methods
Total dissolved solids (mg/L)	Portable conductivity meter HACH	Standard methods
Temperature (°C)	Multiparameter equipment–HACH – Modelo HQ40D	Standard methods
Turbidity (uT)	Turbidimeter HACH 2100P	Standard methods
Styrene (μg/L) (only filtered water for PS filter) (samples collected in the beginning and end of career)	Gas chromatograph (contract laboratory)	SMEWW method 6200 B 21° ed. 2005 (IT 10-355)
Aluminum mg/L (residual)	Spectrophotometer HACH DR/2010	Standard methods

it helped in accelerating the results, and the water treatment plant at Peri Lagoon already has direct filtration technology. The intention was to compare the filtration using polystyrene beads with a similar treatment existing locally. Additional factors include easier construction of the pilot system; the laboratory of UFSC (LAPOA) already has an experimental unit for direct filtration installed in Peri Lagoon.

2.3. Filtered water quality and process control

In the first 30 min, filtered water samples were collected from one filter in one minute to analyze the recovery of the filter. Afterward, raw water samples from two filters were collected every 30 min for an analysis of water quality, as shown in Table 2.

More specifically, for the Styrene analysis, samples were collected at the beginning, middle and end of the filtration runs, as recommended by the contractor SGS Environ, based on the SMEWW method 6200 B 21° ed. 2005 (IT 10-355), and were sent for analysis in São Bernardo do Campo (Sao Paulo–Brazil), with a maximum of 24 h of refrigeration at 4 °C. Altogether, six styrene analyses and six different filtration runs were performed.

Piezometers were installed along the filters. These piezometers served to control the head loss at different depths of the bed, and thus the determination of the depth action. The piezometers were also used to determine the time of the filtration runs. The filter runs were completed when the head loss reached two meters. Ten filter runs were performed, for which the average values and standard deviation of the quality parameters were analyzed, as shown in Table 2. The ten filtration runs also required different time intervals. To establish the average water quality for these different times, we needed to establish the equivalence of the filter run interval. Every filter run interval was assigned the value of 100%. The values for the samples were obtained every 30 min, at percentages equivalent to the filter run interval. Through linear regression, values of water quality from zero to 100% were reached, spread out every 5%. The average results for each filter were compared using a statistical hypothesis test, and a removal percentage.

2.4. Backwashing process

The backwashing of the filters was carried out after the end of the filter runs. Air and water were introduced in an upward direction.

Air was introduced into the lower base of the filter beneath the support layer and dispersed through a system fitted with porous stones. The air was produced by an air compressor with a pressure of 8 kgf/cm^2 and conducted by Teflon hoses. The flow was regulated by a needle valve installed at the entrance of each filter and controlled through a flowmeter with a range of 0–60 NL/min.

The wash water was directed from the filtered water reservoir up to each of the filters by a centrifugal pump 1CV through PVC pipes. At the entrance of each filter was a needle valve that controlled the flow. The flow rate was determined by measuring volume collected in a fixed time.

The backwash processes were different for each filter, as shown below:

2.4.1. Backwashing S + A filter

The velocity of water for backwashing the S + A filter was at 66 m/h (1.1 m/min) for an expansion of 40%. The flow of compressed air was between 48 and 50 NL/min with a pressure of 8 kg/cm ^{2}.

2.4.2. Backwashing PS filter

In accordance with Schöntag and Sens [16], it was found that the minimum fluidizing velocity of PS was 0.89 ± 0.044 m/h. To achieve an expansion of 40%, the water speed was 6.6 m/h (0.11 m/min), which is very small compared to the speeds needed for the expansion of sand and anthracite. The latter ranged from 36 to 72 m/h (0.6 to 1.2 m/min). Thus, two speeds were used: 6.6 m/h and 22.8 m/h (0.11–0.38 m/min) for expansions of 40% and 200%, respectively. In the first backwash process, the PS filter was used with a backwash water velocity of 6.6 m/h (0.11 m/min). For other cases, 200% expansion was used, i.e., a speed of 22.8 m/h (0.38 m/min). The air flow rate used in the backwash of the PS filter was approximately 20 NL/min.

Ten backwash processes were performed, which abide by the following criteria for the two filters: in the first 5 min the air was introduced, after adhering to an interval of 1–2 min (for no loss of material), then followed immediately by 10 min of water. This process was repeated, maintaining a range of 1–2 min.

During cleaning, wash water samples were collected every minute and analyzed for turbidity, which optimized the time of backwashing.

3. Results and discussion

3.1. Filtration systems

The filter run for the S + A filter had an average duration of 9.6 h while the PS filter had an average duration of 5.8 h, or almost half the time for the same production rate. This can be seen in Fig. 2, and relates to the filter run interval with a head loss.

This occurred because the porosity of the beads through the PS is smaller than the porosity of the sand and anthracite filter; the effective size of the grain is evidence of this fact. Furthermore, the large amount of cyanobacteria (*C. raciborski*) causes the penetration (depth filtration) to be low, becoming 40 cm. The presence of two filter elements causes the spread of impurities and achieves greater depths, in the region of 80 cm, as seen in Figs. 3 and 4. The curves presented in Figs. 3 and 4 plot the head loss versus the depth obtained through piezometers installed at different depths of the bed. This made it possible to observe the impurity fronts and depth reached along the media filters.

The recovery period was observed for the ten filtration runs. The average and standard deviation of the apparent color and turbidity of the first 30 min of the filter are presented in Fig. 5.

The recovery time is the time it takes for the filter to stabilize the characteristics of the filtered water. With 95% reliability, the

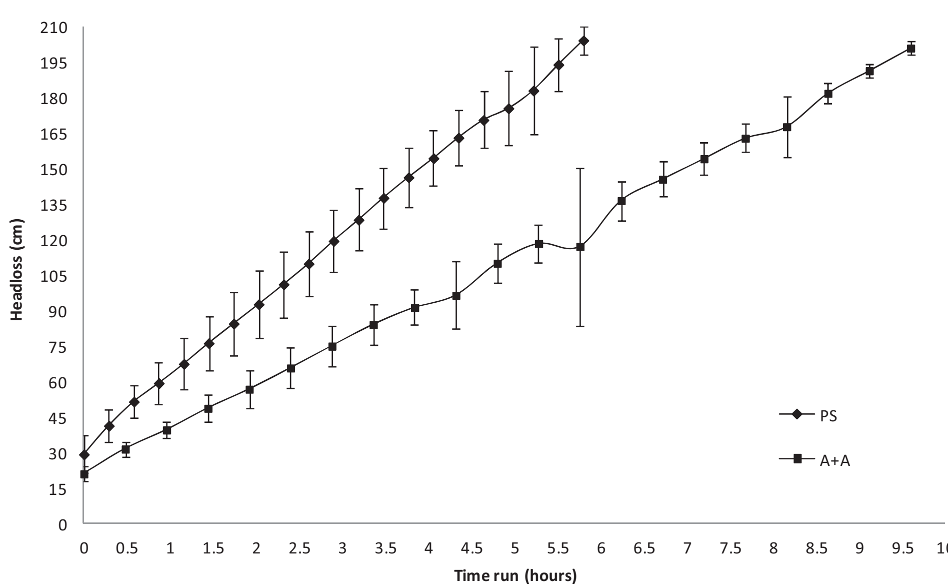

Fig. 2. Average and deflection of head loss of the PS and A + A filters during filtration run.

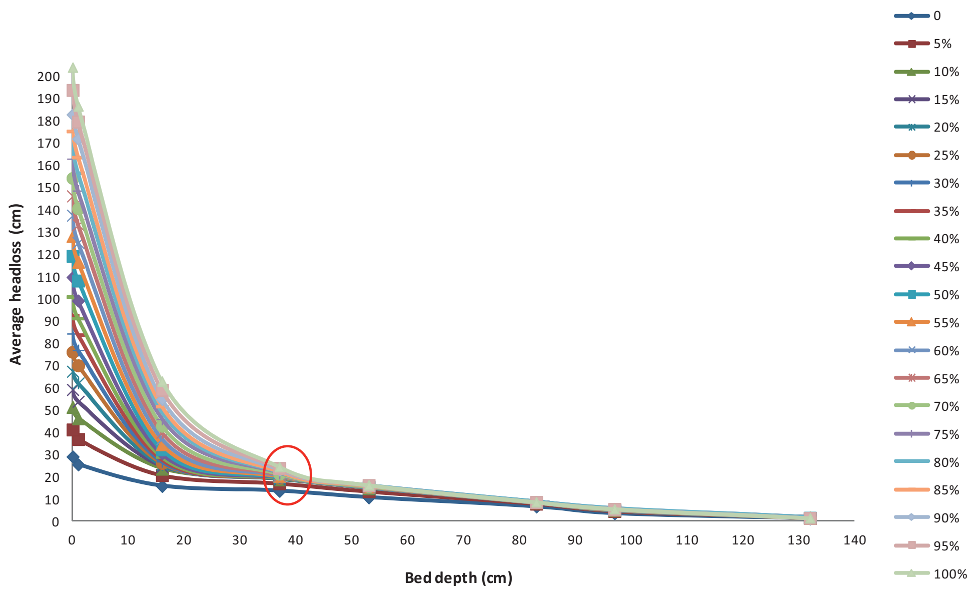

Fig. 3. Depth action of PS filter.

recovery period of the PS filter and the S + A filter shown in Fig. 5 are equal, i.e., 12 min. It was also observed that the quality of the water treated by the PS filter is slightly better than the water treated by the S + A filter, within the first four minutes of filtration, becoming equal by the end of the initial 30 min.

3.2. Filtered water quality

The water quality of the filters was assessed at the baseline and every 30 min. The average, maximum and minimum values are shown in Table 3.

As seen in Table 3, the result of the quality of filtered water is not ideal. This is because the technology of direct filtration is not recommended for raw water with characteristics presented by the water source of Peri Lagoon. This technology was chosen because the turbidity index and true color of the source is low, i.e., less than 10 NTU and 20 nH [5]. However, the elevation of the presence of phytoplankton in the source, and mastering the filamentous species like *C. raciborski* and *P. anabaena* sp. decreased the quality of water produced by the direct rapid filters. However, in this case, the water quality does not invalidate the comparison of these filters. All water quality parameters cited in Table 3 were monitored during the filter runs and are presented below. The pH and water temperature shown were similar, without adding to the results. The percentages of turbidity removal, apparent and true color are shown in Figs. 6 and 7.

The percentage of the removal of turbidity of the PS filter is statistically similar to the S + A filter, with 99% reliability throughout the period of filtration. The percentage of the removal of apparent color, although close, is statistically different, showing an advantage of the S + A filter, with an estimated difference of 2.91 nH. The percentage of the removal of true color (Fig. 7) shows great alternations, but the average values obtained are very close to being 7.25 uH for PS and 8.12 uH for S + A, and are statistically equal with 95% reliability.

In fact, the values of turbidity, apparent color and true color are high, but it is not recommended as a final result for supply. This low removal may be occurring because the raw water from Peri Lagoon,

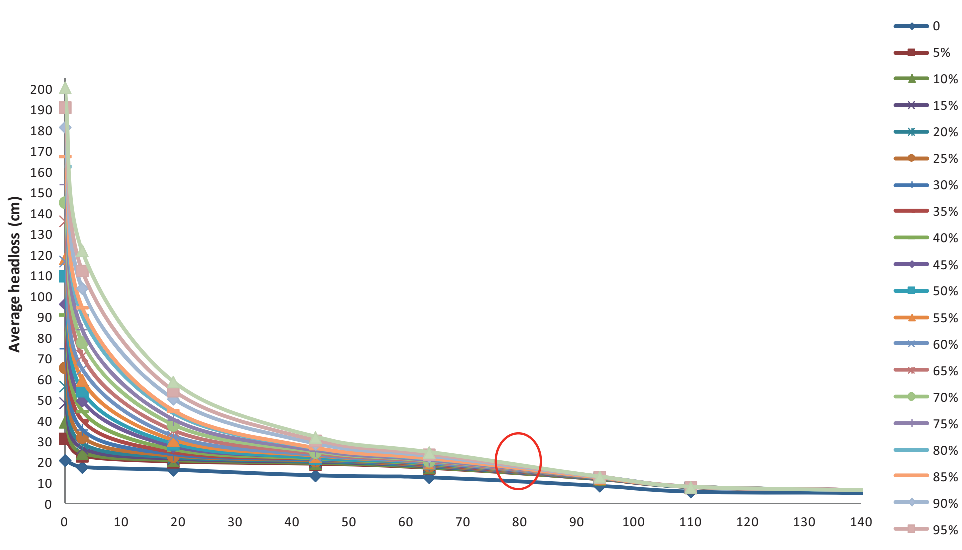

Fig. 4. Depth action of A + A filter.

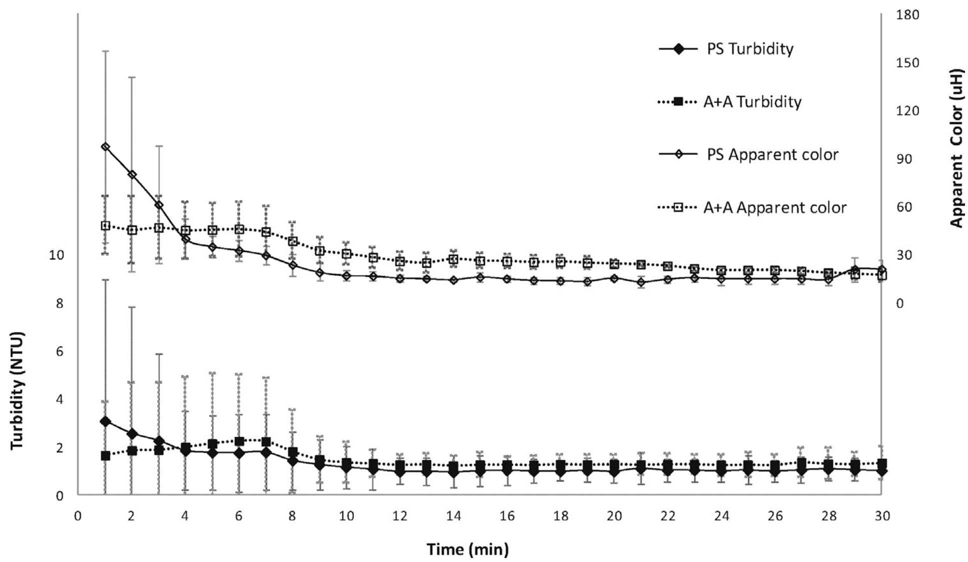

Fig. 5. Average and standard deviation for turbidity and apparent color in the recovery period of ten filter runs for A + A and PS filters.

Table 3
Average values , maximum and minimum water quality obtained from raw water and filtered by the PS and A + A filters.

Parameters	Raw water			Polystyrene filter			Sand/anthracite filter		
	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average
Turbidity (uT)	5.88	4.91	5.5	1.35	0.9	1.28	1.85	0.3	1.31
Apparent Color (uH)	85.6	57.5	75.9	22	5	22.8	24	2	19.7
True color (uH)	15.3	6.7	11.9	10	0	7.25	1	10.5	8.13
Conductivity (μS/cm)	76.2	74.4	75.1	84	81	81.4	99.9	79.9	81
Residual aluminum (mg/L)	[b]	[b]	[b]	0.11	0.02	0.1	0.20	0	0.093
Removal of Cyanobacteria (ind/ml) (*C. raciboski*)	8.48×10^4	4.22×10^4	7.02×10^4	5.25×10^4	1.47×10^4	2.85×10^4	5.61×10^4	1.40×10^4	2.49×10^4
Run filter (h)	[a]	[a]	[a]	7,0	4,5	5,8	6,0	10,5	9,6
Deph bed (cm)	[b]			50			65		
Effective produvtion (%)		89			92				

[b] Values not verified for raw water.

despite displaying low turbidity, has a high concentration of phytoplankton, which would explain these indices, as previously mentioned. The dominant species of phytoplankton is the cyanobacteria *C. raciborski*. Records of these species were completed. The percentages of the removal for each filter are shown in Fig. 8.

The results presented in Fig. 8 shows the percentage of the removal of algae in eight filtration runs. The first run obtained a low removal, between 30 and 40% in the two filters. After the first run, the removal rate increased to 60–70%. During the filtration runs, the PS filter appears more stable, and despite showing similar results, their values were removed with 95% reliability, statistically different to the S + A filter, which shows greater removal. The figures show that the filters are not very effective in removing cyanobacteria and indicate that direct filtration technology is not recommended for the water from Peri Lagoon.

The rates of total dissolved solids and conductivity present similar behavior, with 95% reliability, which are statistically equal. The solubility of aluminum presents similar behavior as well.

The analysis of styrene was performed in six of the ten filtration runs of the water filtered by the PS filter. Analyses were performed

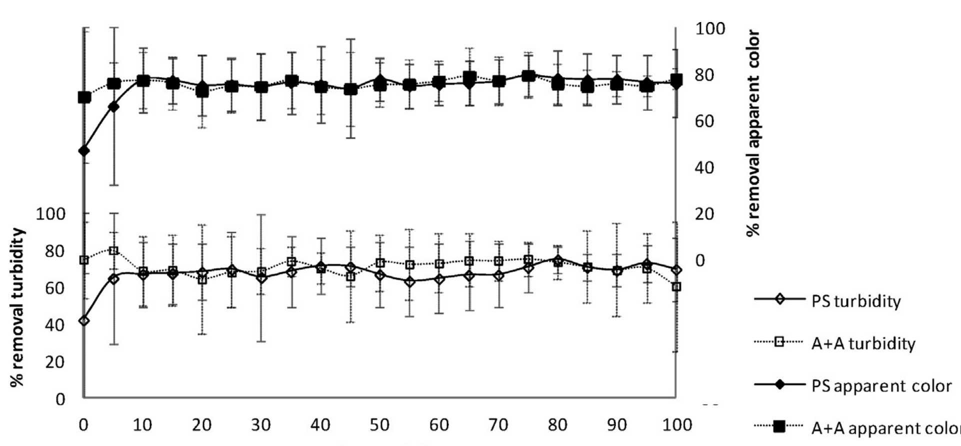

Fig. 6. Average percentage removal of turbidity of filtered water by the A + A and PS filters during filter runs.

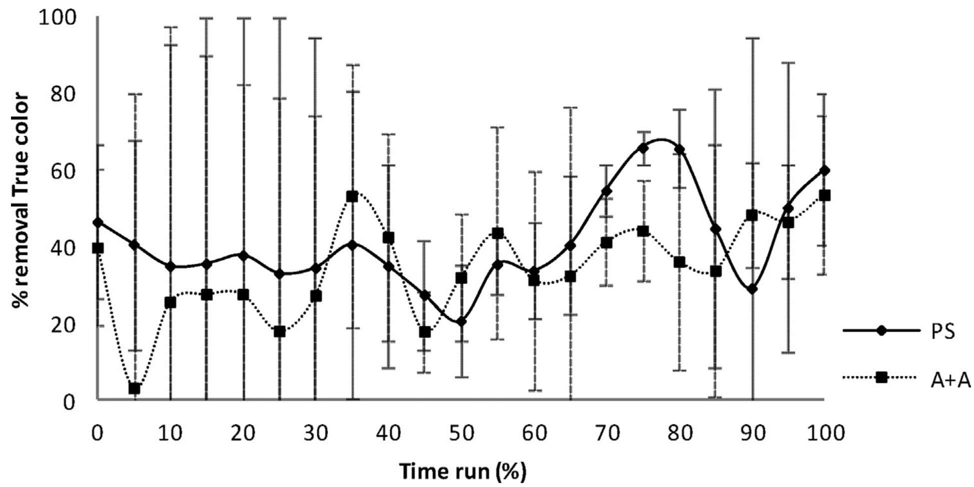

Fig. 7. Average percentage removal of true color of water filtered by the A + A and PS filters during the filter runs.

by the laboratory SGS Environ Ltd. The methodology used by the contracted laboratory was SMEWW 6200 B – 21° ed. 2005 (IT 10-355) by gas chromatography. In reports issued by the laboratory, all samples were below the detection limit, i.e., 4 μg/L. Thus, it is not possible to confirm the presence of this substance. In addition, by ordinance 2.914 of the Ministry of Health of Brazil (Saúde) [15] and the World Health Organization (WHO) [19], the maximum allowed for this element in drinking water is 20 μg/L, and the EPA (Environmental Protection Agency) limit is 100 μg/L [6]; therefore, it is acceptable.

Despite not being detected, care is needed with styrene such that if ingested, it can irritate the gastrointestinal system, causing nausea, vomiting, diarrhea, and depression of the central nervous system, with symptoms such as lethargy, insomnia and dizziness. During ingestion or vomiting, the material can migrate to the lungs, causing seizures, inflammation and pulmonary edema (WHO) [19].

3.3. Backwashing

The backwash process was performed at the end of every filtration run. The entire backwashing process lasted 37 min (air + water) (Fig. 9). The head loss of the fluid filter element was determined, which was approximately 40 cm during the backwashing of the S + A filter.

The results for the S + A filter are shown in Fig. 9. The turbidity of the wash water stabilizes after 3 min of backwashing. This time is sufficient for effective cleaning without wasting treated water.

For the PS filter, backwashing was initially used only for water at a speed of 6.6 m/h (0.11 m/min), i.e., 40% expansion. It was observed that the introduction of water with increased velocity alone is not sufficient to promote the detachment and breaking of the flocs adhered to the PS. These particles adhered to the grains of PS; heavier flocs formed which stuck to the bottom of the filter, as shown in Fig. 10. Thus, the air was applied during the first five minutes of washing. The air carried enough shear, causing the detachment of the adhered particles. After the application of air, water was applied again, with a speed of 6.6 m/h for ten minutes. Although there were agglomerated particles present which adhered to the grains of the PS, the application of water (a superficial velocity of 6.6 m/h (0.11 m/min)) did not have enough force to drag the dirt particles, but promoted the segregation between grains and particles (Fig. 11). In order to increase the drag force, the superficial velocity of the water was increased to 10.8 m/h (12:18 m/min), i.e., an expansion of 100%. It was found that the particles were entrained with the expansion, but not enough to reach the output of the filter. Thus, the superficial velocity was increased again to 22.8 m/h (0.38 m/min), i.e., an expansion of 200%. Only this superficial water velocity was sufficient to remove particles collected during the filtration.

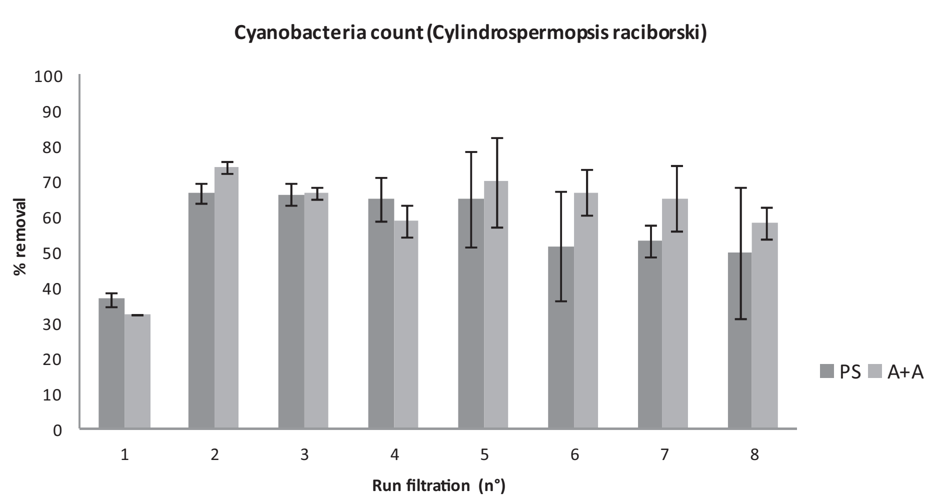

Fig. 8. Average percentage removal of cells of cyanobacteria *C. Raciborski* of water filtered by the A + A and PS filters in different filter runs.

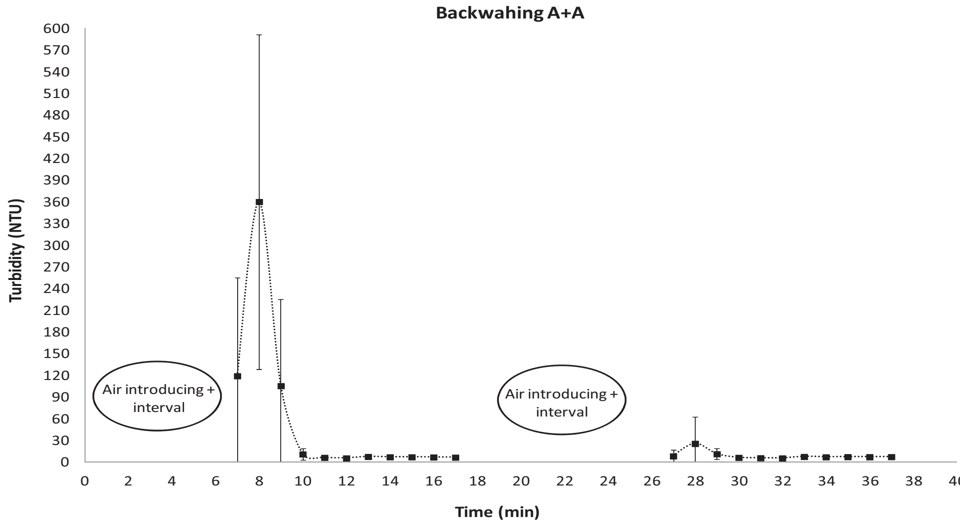

Fig. 9. Turbidity curve obtained during the backwash of the double layer filter of anthracite and sand (average values and standard deviation of a sample of ten runs).

Fig. 10. Particles adhered to PS grains that sediment during the backwashing process, when the water's superficial velocity was 6.6 m/h (0.11 m/min).

Fig. 11. Segregated particles and PS grains with an ascension velocity of 6.6 m/h (0.11 m/min) when the drag force was insufficient.

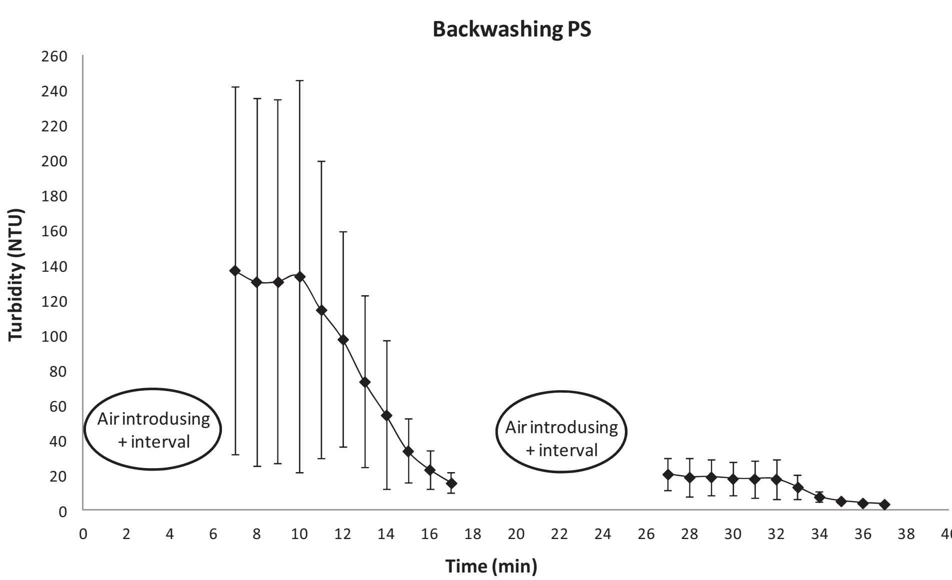

Fig. 12. Turbidity curve obtained during the backwash of the filter with polystyrene granules with growth of 200% in 10 min, i.e., 22.8 m/h (0.38 m/min). (Average values and standard deviation of a sample of ten runs).

The backwash process with an expansion of 200% was achieved. The results can be seen in Fig. 12.

For this velocity, the material takes ten minutes to reach this degree of expansion; it takes longer to clean the filter. When the time of backwashing water is optimized, i.e., 3 min for the S + A filter and 10 min for the PS filter, the actual output values are 92% and 89%, respectively. Although the PS filter has a smaller flow rate during backwashing than that of the S + A filter, the backwash time is greater and has a smaller filtration run, which makes the actual output of the two filters very close. The backwash process should be better observed. The exit point of the wash water should be altered and other flow rates and degrees of expansion should be analyzed. Future tests will be conducted in order to optimize the surface speed and the length of both the backwash water and air in order to verify the use of this material as a media filter with economized wash water.

4. Conclusions and recommendation

In all the parameters of analyzed quality, the water produced by the PS filter proved to be very similar to the S + A filter, despite the statistical differences. PS granules do not release detectable amounts of styrene in water and can therefore be used as a filter element. Nevertheless, the material must be monitored over the long term in order to verify its degradation, and the possibility of the release of styrene or byproducts into the water.

Overall, the two filters achieved a similar performance. The big difference between the filters was the length of the filter runs and the approximate speed of the water during backwashing, due to the low specific weight of the PS filter. The length of the filter run of the PS filter was 1.65 times shorter than that of the S + A filter. Being a granular element with virtually spherical grains and small grain size, it presents lower bed porosity, causing the head loss of the PS filter to reach two meters more quickly, thus ending the runs early. In contrast, the approximate speed of the water during backwashing can be up to three times lower, and the time required for an efficient cleaning was 3.3 times higher, considering the optimal time.

At first, the actual production of the PS filter was practically the same as the S + A filter, showing advantages in using this new material. The relationship between approximate speed and backwash time still requires further analysis. The time and velocity can be improved and optimized, so that effective production of the PS filter may be superior to the S + A filter, generating savings in the process.

One advantage presented by the PS material was a low head loss during backwashing. The head loss of the PS fluid filter was up to 15 times smaller than that presented by the S + A filter. Being lightweight, it can be easily fluidized. This feature can assist the cleaning process, generating savings; as stated by Šećerov Sokolović et al. [17], using expanded polystyrene has the great ability to reduce capital and operational costs when systems are optimized. It not only economizes water volume, but reduces the size of the reservoirs with smaller dimensions and smaller diameters of pipes/valves, and uses pumps with less power.

Acknowledgements

The author acknowledges the support of the FINEP/HABITARE, FAPESC/PRONEX and CNPQ (National Council of Technological and Scientific Development, Brazil).

References

[1] Ö Akgiray, A. Saatçi, A new look at filter backwash hidraulics, Water Supply 1 (2) (2001) 65–72.
[2] L. Di Bernardo, A. Dantas, Método e Técnicas de Tratamento de Água São, RiMa, Carlos – SP, 2005.
[3] M. Boller, M. Kavanaugh, Particle characteristics and headloss increase in granular media filtration, Water Res. 29 (4) (1995) 139.
[4] J. Crittenden, R. Trussell, D. Hand, K. Howe, G. Tchobanoglous, Water Treatment Principles and Design, MWH, John Wile & Sons, Hoboken, NJ, 2011.
[5] R.L. Dalsasso, M.L. Sens, Filtração direta com pré-floculação e coagulação com sulfato de alumínio e hidroxicloreto de alumínio: estudo com água de manancial eutrofizado, Eng. Sanit. Ambient. 11 (3) (2006) 241–249.
[6] E.P.A. EPA, Consumer Factsheet on: STYRENE., 2. http://water.epa.gov/drink/contaminants/basicinformation/styrene.cfm (2014).
[7] R. Fabris, C.W.K. Chow, M. Drikas, B. Eikebrokk, Comparison of NOM character in selected Australian and Norwegian drinking waters, Water Res. 42 (15) (2008) 4188–4196 (accessed 11.8.12) http://www.ncbi.nlm.nih.gov/pubmed/18706670
[8] B. Farizoglu, A. Nuboglu, E. Yildiz, B. Keskinler, Performance of pumice as a filter bed material under rapid filter, Filtr. Sep. (Abril) (2003) 41–46.
[9] D. Harwanto, S. Oh, J. Jo, Comparison of the nitrification efficiencies of three biofilter media in a freshwater system, Fish Aqua. Sci. 14 (November) (2011) 363–369.
[10] B. Hsu, C. Huang, J.R. Pan, Filtration behaviors of giardia and cryptosporidium ionic strength and ph effects, Water Res. 35 (16) (2001) 3777–3782.
[11] P. Knudsen, The effect of media selection on filtration performance, Process Eng. – Sydney Australia 8 (4) (1980), ISSN 0159-3935.
[12] R. Mondardo, Avaliação da Filtração em Margem como Pré-Tratamento à Filtração Direta Descendente na remoçãode células de Cianobactérias e Saxitoxinas (Florianópolis/SC, ed.), Tese de doutorado – Programa de Pós-graduação em Eng. Ambiental – UFSC. (2009) http://onlinelibrary.wiley.com/doi/10.1002/cbdv.200490137/abstract
[13] P. Pearce, S. Jarvis, Operational experiences with structured plastic media filters: 10 years on, Water Environ. J. 25 (2) (2011) 200–207 (accessed 11.09.12) http://doi.wiley.com/10.1111/j.1747-6593.2009.00210.x
[14] L.G. Romero, R.I. Mondardo, M.L. Sens, T. Grischek, Removal of cyanobacteria and cyanotoxins during lake bank filtration at Lagoa do Peri, Brazil, Clean Technol. Environ. Policy 16 (6) (2015) 1133–1143 (accessed 12.10.14) http://link.springer.com/10.1007/s10098-014-0715-x
[15] M. Saúde da, Portaria 2. 914 do Ministério da Saúde. (2011) 2–32.
[16] J.M. Schöntag, M.L. Sens, Characterization of polystyrene granules as granular media filters, Desalin. Water Treat. (June) (2014) 1–13 (accessed 07.27.14) http://www.tandfonline.com/doi/abs/10.1080/19443994.2014.928234
[17] R. Šećerov Sokolović, S. Sokolović, D. Govedarica, Performance of expanded polystyrene particles in deep bed filtration, Sep. Purif. Technol. 68 (2) (2009) 267–272 (accessed 11.10.14) http://linkinghub.elsevier.com/retrieve/pii/S1383586609002238
[18] A. Sierra Filho, A. Mattos, F. Calò, Meio Filtrante ò base de Pomes e tela Termoplàstica – Alternativa para a filtraáço de à gua potàvel (2005) 17.
[19] WHO, Styrene in Drinking-water Background document for development of WHO Guidelines for Drinking-water Quality, 2, WHO, 2003, pp. 1–7.
[20] H. Zhu, D. Simith, W.H. Zhou, S.J. Stanley, Improving removal of turbidity causing materials by using polymers as a filter aid, Water Res. 30 (1) (1996) 103.