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Low-cost Packing Materials in an Aerated Biofilter for Lagoon Effluent Treatment

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Abstract

As part of a comprehensive evaluation of post-treatment techniques for the removal of chemical and microbiological pollutants from lagoon effluents, an aerated biofilter was designed. The main objective of this study was to evaluate the performance of pozzolan and *Luffa cylindrica* as low-cost packing materials for the advanced treatment of Stidia natural lagoon effluent. The aerated biofilter operates in down-flow with *HLR*s of 11.37 to 28.43 $m^3\,m^{-2}\,d^{-1}$ and an air/liquid flow ratio of 3 : 1. The different experiments performed on the pilot showed that the percentages of sCOD removal vary with the *HLR*s and the wastewater concentration at the biofilter inlet. In this study, sCOD removal efficiencies above 78.9 % were achieved depending on *HLR*, and a maximum removal efficiency of TSS of 71.5 % was obtained for 28.43 $m^3\,m^{-2}\,d^{-1}$. At low *HLR* (11.37 $m^3\,m^{-2}\,d^{-1}$), the treated effluent had the following average concentrations: sCOD of 29.5 $mg\,l^{-1}$, BOD_5 of 21.7 $mg\,l^{-1}$ and TSS of 26.4 $mg\,l^{-1}$. These experimental results were used with an empirical model to determine the media constant *n* and treatability factor *K*. The faecal coliforms and *Escherichia coli* detected in the treated effluent were less than 10^5 CFU/100 ml, which meet the national guidelines for wastewater reuse in irrigation.

Keywords

Natural lagoon, wastewater reuse, aerated biofilter, Luffa cylindrica, pozzolan

1 Introduction

Wastewater reuse is an important contribution to wastewater reclamation that has attracted the attention of many researchers in recent years.[1–3] Generally, facultative lagoon effluents are considered as secondary effluents that meet standards for discharge into water courses.[4] For wastewater reuse, higher standards are required and facultative lagoon treatment alone will not be sufficient. Thus, advanced treatments must be developed to improve quality of facultative lagoon effluent to meet stringent discharge standards. For additional treatments, maturation lagoons must be constructed in series. However, these methods require large areas of land and additional operating costs.[4] Replacing maturation lagoons with expensive treatment systems can be a significant economic burden for local public authorities. Thus, the obvious choice is to find a simple, low-cost method such as biofiltration to upgrade facultative lagoon to meet standards for wastewater reuse in irrigation. It is clear that when treating secondary wastewater by biofiltration, the daily volumes of treated water will be relatively small. This may be sufficient for drip irrigation, which is a water-saving technique and gives better yields.

Biofiltration has been developed precisely for tertiary treatments and mainly for nitrification/denitrification processes.[5–7] The material used in biofiltration must have a rough surface for good biofilm development and an effective particle diameter that must allow for an adequate void ratio to ensure a good wastewater flow through the filter bed. Natural porous volcanic rocks (pumice, pozzolan, scoria, *etc.*) have already been tested as granular materials in biofilters for wastewater treatment. They are low-cost, locally available and have properties suitable for biofilm formation.[8] Several researchers[9–12] have investigated the performance of pumice and pozzolan as biofilter materials for the removal of carbonaceous, phosphorous and nitrogenous matters from wastewater. *Kuslu et al*.[13] studied pumice combined with sand and gravel as filter media under different pressure filtration conditions, and found that pumice achieved the best solid removal efficiency.

In recent years, *Luffa cylindrica*, a non-toxic and biodegradable plant variety, has been processed into activated carbon for use as low-cost adsorbent,[14] as a soil amendment in arid zones to retain irrigation water[15], and as bed media filtration for wastewater treatment in trickling filters.[16] *Wang et al.*[17] reported that *L. cylindrica* was more suitable as a carrier than plastic sponge in sequencing batch biofilm reactor. *Zhang et al.*[18] studied the start-up characteristics of *L. cylindrica* biofilm reactor for domestic wastewater treatment and found that 10 days was sufficient for complete acclimation of microorganisms. *L. cylindrica* was used as a carrier in an aerobic biofilm reactor for biodegrading hydrolysed polyacrylamide from artificial wastewater,[19] and for treating effluent from fish ponds.[20]

This study focuses on the reuse of treated wastewater in drip irrigation by improving the physicochemical and microbiological quality parameters of Stidia lagoon effluent through biofiltration using local environmentally friendly materials. To our knowledge, no attempt has been made to upgrade the wastewater of Stidia lagoon. A layer of *L. cylindrica* (upper layer, 20 cm) in the biofiltration column was used as a support to promote biofilm formation, and at

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the same time prevent the rapid clogging of the pozzolan bed (100 cm, bottom layer). This, therefore, underlines the novelty in this study.

2 Materials and methods

2.1 Location of Stidia natural lagoon

The wastewater investigated in this study was collected from the natural lagoon near the city of Stidia in Mostaganem, northwestern Algeria. It is located 10 m above sea level at latitude 35° 49' 40" N and longitude 0° 0' 54" W . The average air temperature in this area ranges from 10.5 °C in January to 37.5 °C in July (annual average temperature is 17.5 °C).[21] As shown in Fig. 1, the different sampling sites of raw wastewater (RW) at the discharge zone just at the lagoon entrance are labelled RW1, RW2, and secondary wastewater (SW) following UV exposure at the opposite side of the entrance is indicated as SW1 and SW2.

Fig. 1 – Overview of Stidia natural lagoon

2.2 Wastewater analyses

Turbidity and conductivity were measured using a WTW turbo 550IR turbidity meter and a conductivity meter (Levibond SensoDirect Con200). For COD analysis, the closed reflux digestion and titrimetric method were used according to the Standard guidelines.[22] The pH, DO and temperature were measured using a pH meter (model HI-2210, Hanna instruments) and a portable dissolved oxygen meter (Hanna instruments, model HI-98193). TSS, faecal coliforms and *Escherichia coli* were determined after filtration of the water samples through 0.45 µm pore size (47 mm diameter) cellulose membrane using a vacuum system according to the procedures outlined in APHA.[22]

2.3 Biofilter media preparation

The volcanic rock used in this study as filter media was pozzolan, a locally available material collected from the mountain area of the Beni-Saf region in northwestern Algeria (35° 16' 58.81" N and 1° 24' 24.99" W). Pozzolan is a natural basaltic rock with 40–50 % of silica (SiO_2).[23] The stones were extracted in different sizes, and those with a vesicular structure and low weight were selected on site. Once brought back to the laboratory, they were crushed and sieved to obtain different grain sizes. The effective diameter was determined using international standard sieves (1.00 mm, 1.12 mm, 2.00 mm, 2.50 mm, and 3.15 mm).

Dried peeled fruit (sponge) of the *L. cylindrica* plant was used in this study as pre-treatment layer in the upper part of the biofilter because of its highly branched fibrous and light structure. The *L. cylindrica* columns were purchased from local market at low price; they were mature and dried. In the laboratory, each column was cut into cylindrical shapes 20 cm long. They were then treated in a solution of 0.25 M NaOH for 12 h at room temperature to improve their mechanical properties and increase surface roughness of fibres.[24]

2.4 Experimental set-up

A transparent column made of polyvinyl chloride fed from the top was set-up for this study (Fig. 2). The biofilter column had a total height of 160 cm and consisted of a 16-cm diameter lower part filled with 100 cm of pozzolan, and a 22-cm diameter upper part filled with 20 cm of *L. cylindrica*. The packed bed of *L. cylindrica* was constructed by vertically inserting similar 20-cm long cylindrical shapes inside the column. The entire assembly should form a compact and compressed filter cartridge. The bed must be maintained submerged 5 cm below the water level during the experiments. As the wastewater flows through the biofilter, the impurities will accumulate over time on the surface of the top layer of filtration material. This accumulation will eventually clog the surface of the bed, the flow becomes slow and the biofilter will be put out of service. When this situation occurs, the *L. cylindrica* cartridge should be removed, washed, and reused again. This solution should avoid costly backwashing sequences. The materials in the column were retained on a 10-mm thick perforated Plexiglas disk located at the bottom of the column, and another 4-mm thick perforated Plexiglas disk was inserted between the two layers to prevent mixing between them. An air compressor supplied two fine bubble air diffusers

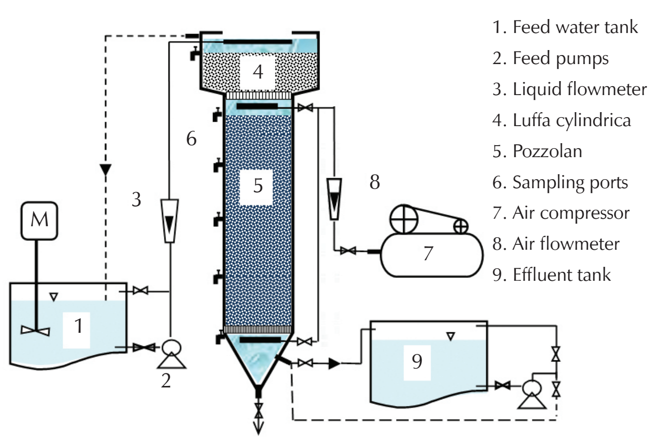

Fig. 2 – Schematic of biofiltration pilot

positioned under each layer of material. At the beginning of the first experiments, the materials were washed with tap water before introduced into the filter column.

The wastewater to be treated was pumped continuously with a feed pump from a 100-l storage tank to the top of the filtration column at influent flow rates in accordance with the selected *HRT*s. To monitor the flow of the influent, a Brooks flowmeter was connected to the feed pipe. The column was opened at the top to allow the evacuation of stale air.

Since the removal of organic matter and suspended solids by biofiltration is due to biodegradation, an acclimation period is required for the biofilter to allow the microorganisms present in the influent to attach and colonize the surface of the filter media, and to produce an adequate biofilm. Typical acclimation periods are from 2 to 4 weeks in closed loop depending on operating conditions.[25–27]

In this study, the column was inoculated with biomass derived from an activated sludge plant treating municipal wastewater. The system was operated in closed circuit under aeration for several days. The acclimation period took approximately 15 days with a flow rate of 1 $l\,h^{-1}$ and discontinuous feedings. As the *L. cylindrica* has a complex interconnected pore structure, a rapid change in its colour was observed, indicating the formation of a biofilm during this acclimation period. The experiments were performed continuously each day according to *HRT*s, and all tests took three months. For each run, sCOD and TSS of the influent and effluent were measured in triplicate.

2.5 Experimental determination of removal efficiency and medium filter constants

Based on previous models for trickling filters,[28,29] an empirical model for biofilters was developed by *Mann et al*.[25] in which influent sCOD concentration was related to effluent sCOD concentration at bed height *h* for specific filter media:

$$\frac{S_h}{S_0} = \exp\left(-\frac{KAh}{QS_0^n}\right) \tag{1}$$

where *n* is constant depending on filtration media, and *K* (mg sCOD/L)^n d^{-1} is the treatability factor.

In order to calculate *n* and *K*, Eq. (1) would be rewritten as:

$$\text{—} = \exp(-mh) \tag{2}$$

where *m* is K/qS_0^n and *q* equals *Q*/*A*.

Therefore, by plotting $\ln(S_h/S_0)$ against h, the slope ($-m$) was obtained for different values of S_0. From the plot of $\ln(mq)$ against $\ln(S_0)$, the values of *n* and *K* were determined.

The removal efficiency *E* was calculated with the following equation:[30]

$$E(\%) = \left(1 - \frac{S_h}{S_0}\right) \cdot 100 \tag{3}$$

2.6 Hydraulic retention time

The *HRT* is defined as the time that it takes for influent to flow through the bed medium height of the column, and was calculated by Eq. (4):

$$HRT = \frac{\varepsilon_p}{Q} \tag{4}$$

The packing bed void ratio ε_p can be determined using Eq. (5):

$$\varepsilon_p = \frac{\text{total volume} - \text{solid packing volume}}{\text{total volume}} \tag{5}$$

2.7 Water retention measurements

The water adsorption fraction of the medium, F_{ad} can be calculated by the following equation:

$$F_{ad} = \frac{m_{lc}}{m_{dp}} \tag{6}$$

The amount of liquid captured in the material is the difference between the weight of the moist packing after drainage and the weight of the dry material packing.

The water retention capacity, R_c, was calculated by Eq. (7):

$$R_c = \frac{V_{lc}}{V_{sp}\left(1-\varepsilon_m\right)} = F_{ad}\frac{\rho_s}{\rho_l\left(1-\varepsilon_m\right)} \tag{7}$$

3 Results and discussion

3.1 Lagoon wastewater characteristics

Since the 1970s, the wastewater generated by the population of Stidia city (estimated at 12651 inhabitants in 2012)[31] is discharged into a main collector that leads to the natural lagoon. The average rainfall and the wastewater quality parameters expressed as a minimum-maximum range, collected at the locations RW1 and RW2 (Fig. 1), are presented in Table 1. Due to the seasonal variations, the composition of the wastewater resulted in fluctuation of the physicochemical parameters (Table 1).

Table 1 – Stidia lagoon influent quality

Period 2019–2020	Rainfall / mm year^{-1}	pH	BOD_5 / mg l^{-1}	*t*COD / mg l^{-1}	TSS / mg l^{-1}
summer	23±5	6.3–8.2	109–283	228–594	115–167
winter	128±10	6.6–7.9	113–314	251–653	105–120
spring	156±30	6.5–8.1	105–306	214–482	118–147

Stidia lagoon has the advantage of being located in a region that has three seasons, based on average rainfall and temperature trends: summer (June-September), winter (October-January), and spring (February-May), which are characterised by low, short/moderate, and heavy rainfall, respectively.[31] When comparing seasonal variations of the different parameters in Table 1, lower BOD_5 and *t*COD values were found in spring season due to the combined effect of rainfall and temperature elevation (18–34 °C). This phenomena stimulates heterotrophic bacteria to consume large amounts of organic contaminants and DO.[32] TSS concentrations were dependent on the season, with values ranging from 105 mg l^{-1} to 167 mg l^{-1} (Table 1).

A total of 30 wastewater samples were collected during a period of three months, from May to July 2020 at the different locations indicated in Fig. 1. The results presented in Table 2 show that there was substantial variability in physicochemical parameters with relatively large deviation during the investigated period. The ratio of BOD_5/sCOD ≥ 0.63 indicated that the SW was suitable for biologically treatment, *i.e.,* it was biodegradable without pretreatment.[32,33] TSS concentrations in SW ranged from 70 mg l^{-1} in May to 110 mg l^{-1} in July. These monthly variations in TSS are related to the growth of algae, stimulated by the increase in temperature and solar radiation.

Table 2 – Wastewater composition (main parameters) during the experimental period

Parameter	RW	SW	Algerian Standards[34]
pH-value / –	8.2 ± 0.1	7.6 ± 0.4	6.5–8.5
turbidity / NTU	70.5 ± 1.1	30.8 ± 1.2	–
conductivity / µS cm^{-1}	2588.4 ± 7.5	2650.1 ± 6.3	3000.0
TSS / mg l^{-1}	157.5 ± 21.9	95.8 ± 15.6	30.0
tCOD / mg l^{-1}	263.2 ± 2.4	215.3 ± 3.5	–
sCOD / mg l^{-1}	185.1 ± 5.3	153.4 ± 6.1	90.0
BOD_5 / mg l^{-1}	109.1 ± 4.5	97.1 ± 3.4	30.0
total N / mg l^{-1}	59.5 ± 2.3	46.8 ± 3.1	30.0
DO / mg l^{-1}	1.3 ± 0.3	1.7 ± 0.2	–
S A R / meq l^{-1}	4.5 ± 0.1	3.1 ± 0.2	< 3.0

Data are means ± standard deviation for each analysed parameter, determined on 30 samples for each water type.

The effluent from this lagoon failed to meet the national standards of reuse, based on the results of the analysis (Table 2). However, as this wastewater contains the major plant nutrients, it can be used for fertilization of the crops in this zone. The only problem is the over-fertilisation, which should be avoided by dilution of this wastewater with natural waters to control nutrients and heavy metal concentrations in the irrigation water.

3.2 Performances of the biofilter column

The physical characteristics of the pozzolan were determined in the laboratory and the results, as well as some calculated parameters, are presented in Table 3.

Table 3 – Physical properties of pozzolan

Grain size / mm	Effective diameter D_{10} / mm	Uniformity coefficient $U = D_{60}/D_{10}$	ρ_s / kg m^{-3}	ε_m / %	ε_p / %
1.12–3.15	1.37	1.43	791.38	67.49	45.10

The physical properties and chemical composition of *L. cylindrica* depend on several factors, such as plant origin and weather conditions[35]. The *L. cylindrica* used in this study had the same core topology, with a compact structure and a density within the range of 52±1 kg m^{-3}.

The retention capacities of the filtration materials are presented in Table 4. The maximum retention for the pozzolan was 17%, while for the *L. cylindrica* it was 35%, indicating a significant hydro-expansion of this material. This particularity was also observed by *Wang et al.*[17] in the comparative study of *L. cylindrica* with plastic sponge.

Table 4 – Retention capacities of filtration media- pozzolan and *L. cylindrica*

Media filtration		m_{dp} / kg	m_{lc} / kg	F_{ad} / –	R_{lc} / –
pozzolan	1.12–3.15 / mm	11.72	1.28	0.11	0.17
L. cylindrica		0.47	0.78	1.68	0.35

Fig. 3 shows the evolution of sCOD concentrations over the height of the bed media at different hydraulic loading rates. The sCOD removal efficiency was about 25 % for the 20-cm layer of *L. cylindrica* and over 50 % for 100 cm of pozzolan.

It was observed that when influent sCOD concentration was maintained constant, the effluent sCOD concentration increased with increasing *HLR*. However, as the *HLR* increased, the contact time between the biofilm and the percolating liquid decreased, resulting in a decrease in the removal efficiency.

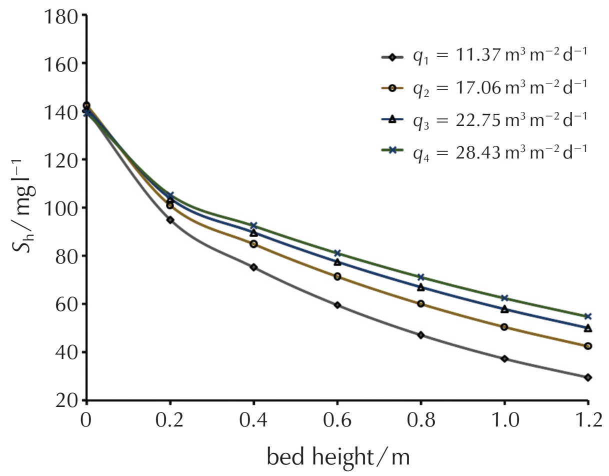

Fig. 3 – sCOD removal profiles at different *HLR*s at S_0 = 140 mg l^{-1}

Fig. 4 illustrates the effect of *HRT* investigated (1–12 h) on the sCOD removal efficiency at different influent concentrations. An improvement in sCOD removal efficiency was observed with increasing *HRT* for all influent concentrations. On the other hand, the removal efficiency decreased with increasing influent concentration.

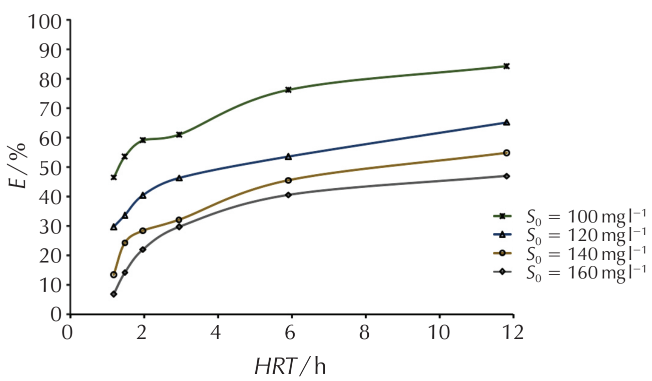

Fig. 4 – Effect of *HRT* and influent concentration (S_0) on the sCOD removal efficiency

The maximum TSS removal was achieved when the biofilter was operated for a long time. When the biofilter was fed with an influent containing an average TSS concentration of 83.60 mg l^{-1} and the *HLR* maintained at 28.48 m^3 m^{-2} d^{-1}, the lowest TSS concentration obtained in the final effluent was approximately 23.80 mg l^{-1} and removal efficiency was 71.5 %. It has been reported that for long operation, the fine particles agglomerate in the lower part of the filter bed, and that at a given loading rate, a medium with small grain size (D_{10} < 1 mm) will give better removal but will have an effect on subsurface clogging.[13,37]

The values of the constants n and K were obtained from the plots of ln(mq) against ln (S_0) at different *HLR*s (Fig. 5). The differences in values of K found from the experimental results depended on *HLR*s: as q increased, the value of K decreased. The treatability factor K will increase as the sCOD removal rate increases.

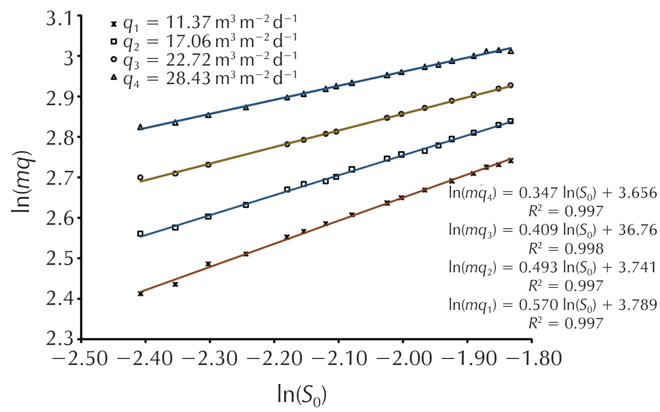

Fig. 5 – Relation between mq and influent sCOD concentration (S_0)

Table 5 summarizes the values of n and K obtained in this study and compares them to the different values obtained by other researchers in previous studies. In this study, the K values obtained were in good agreement with the values determined in other studies. They are slightly higher than those of Lava, which is probably due to the difference in surface properties between the two materials.

The main microbiological parameters, *Escherichia coli* and faecal coliforms of SW and of treated wastewater are presented in Table 6. Despite the exposure of the wastewater to solar UV, the average values of *E. coli* and faecal coliforms in the SW samples remained above the limits recommended by WHO.[36]

Table 5 – Comparison of n and K from derived models in the literature with the present results

Bed medium	Diameter / mm	S_0 / mg l^{-1}	q / m^3 m^{-2} d^{-1}	K / (mg l^{-1})^n d^{-1}	n / –	Reference
sunken media	2.30–2.70	80–210	9.23–18.15	33.0	0.92	*Mann and Stephenson*[25]
floating media				55.0	1.13	
lava	3.00–5.00	100–201	9.17–22.01	36.5–44.0	0.21–0.71	*Wang et al.*[26]
expanded clay				31.5–38.0	0.21–0.66	
pozzolan	1.12–3.15	80–160	11.37–28.43	38.7–44.2	0.35–0.57	this study

Table 6 – Typical microbiological parameters of secondary and treated effluent

Parameter	SW	Treated wastewater	Standards[34,36]
E. coli / log CFU/100 ml	5.26 ± 0.60	4.12 ± 0.11	<5 for restricted irrigation <3 for unrestricted irrigation
Faecal coliforms / log CFU/100 ml	5.64 ± 0.47	4.81 ± 0.79	

Data are means ± standard deviation for each analysed parameter, determined on 16 samples for each water type.

Significant removal of *E. coli* and faecal coliforms was achieved during the experimental period. The average values for *E. coli* and faecal coliforms in the treated wastewater were $1.30 \cdot 10^4$ CFU/100 ml and $6.24 \cdot 10^4$ CFU/100 ml, respectively, corresponding to a removal efficiency of 85.2 % for faecal coliforms, and 92.7 % for *E. coli*. These reductions did not vary significantly with *HLR*s.

4 Conclusion

Biofiltration was investigated as an alternative method for tertiary treatment of secondary effluent from Stidia natural lagoon. The biofilter filled with a 100-cm layer of pozzolan and a 20-cm upper layer of *L. cylindrica* was operated at different *HLR*s from May 2020 to July 2020.

The removal efficiency of sCOD was greater than 78.9 %, depending on *HLR*, and a maximum TSS removal efficiency of 71.5 % was achieved at 28.43 $m^3\,m^{-2}\,d^{-1}$. The low *HLR* resulted in an effluent with average TSS of 26.4 $mg\,l^{-1}$, sCOD of 29.5 $mg\,l^{-1}$, BOD_5 of 21.7 $mg\,l^{-1}$ and less than 5.0 log CFU/100 ml.

Based on the results presented above, the biofiltration of the secondary effluent from the natural lagoon of Stidia using pozzolan and *L. cylindrica* can produce an effluent meeting the requirements of effluent standards for reuse.

For further investigations, a similar experimental work using biofilters of larger dimensions operating in parallel would be the next step. Another investigation to be recommended is the analysis of the physical stability of *L. cylindrica* fibres during the time it remains in activity as a filter medium.

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List of abbreviations and symbols
Popis kratica i simbola

HLR – hydraulic loading rate, $m^3\,m^{-2}\,d^{-1}$
COD – chemical oxygen demand, $mg\,l^{-1}$
sCOD – soluble chemical oxygen demand, $mg\,l^{-1}$
tCOD – total chemical oxygen demand, $mg\,l^{-1}$
BOD_5 – biochemical oxygen demand over 5 days, $mg\,l^{-1}$
DO – dissolved oxygen, $mg\,l^{-1}$
TSS – total suspended solids, $mg\,l^{-1}$
HRT – hydraulic retention time, h
S_0 – influent sCOD concentration, $mg\,l^{-1}$
S_h – effluent sCOD concentration, $mg\,l^{-1}$
Q – volumetric flow rate, $m^3\,h^{-1}$
A – cross sectional area of the column, m^2
q – hydraulic loading rate (Q/A), $m^3\,m^{-2}\,d^{-1}$
V – volume of the column packed with bed medium, m^3
V_{lc} – liquid holdup volume, m^3
V_{sp} – solid packing volume, m^3
m_{lc} – amount of liquid captured in the material, kg
m_{dp} – weight of dry material packing, kg
ρ_l – liquid density, $kg\,m^{-3}$
ρ_s – particle density, $kg\,m^{-3}$
ε_m – particle porosity, –
SAR – sodium adsorption ratio, $meq\,l^{-1}$
CFU – coliform faecal unit
SW – secondary wastewater
RW – raw wastewater

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SAŽETAK

Primjena jeftinih punila u aeriranom biofiltru za pročišćavanje efluenta laguna

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U sklopu sveobuhvatne procjene tehnika naknadnog uklanjanja kemijskih i mikrobioloških onečišćenja iz efluenta laguna, projektiran je aerirani biofiltar. Glavni cilj ovog istraživanja bio je procijeniti učinak pucolana i biljke *Luffa cylindrica* kao jeftinih punila za naprednu obradu efluenta prirodne lagune Stidia. Aerirani biofiltar radi s brzinom hidrauličkog opterećenja (*HLR*) od 11,37 do 28,43 $m^3\,m^{-2}\,d^{-1}$ i omjerom protoka zrak/tekućina od 3 : 1. Eksperimenti provedeni na pilotu pokazuju da smanjenje KPK (izražene s obzirom na otopljene tvari) varira ovisno o *HLR*-u i koncentraciji otpadne vode na ulazu u biofiltar. U ovom istraživanju postignute su učinkovitost smanjenja KPK iznad 78,9 % ovisno o *HLR*-u, a maksimalna učinkovitost uklanjanja ukupnih suspendiranih čestica (TSS) od 71,5 % dobivena je pri 28,43 $m^3\,m^{-2}\,d^{-1}$. Pri niskom *HLR*-u (11,37 $m^3\,m^{-2}\,d^{-1}$), KPK, BPK_5 i TSS obrađene otpadne vode iznosili su 29,5 $mg\,l^{-1}$, 21,7 $mg\,l^{-1}$ odnosno 26,4 $mg\,l^{-1}$. Ti eksperimentalni rezultati korišteni su u empirijskom modelu da bi se odredila konstanta medija *n* i faktor obrade *K*. CFU vrijednosti fekalnih koliforma i bakterije *Escherichia coli* u obrađenoj otpadnoj vodi bile su ispod 10^5 CFU/100 ml što zadovoljava nacionalne smjernice za upotrebu tih voda u navodnjavanju zemljišta.

Ključne riječi
Prirodna laguna, ponovna upotreba otpadne vode, aerirani biofiltar, Luffa cylindrica, pucolan

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