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Review

Date-palm fibers media filters as a potential technology for tertiary domestic wastewater treatment

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ABSTRACT

A number of municipal wastewater treatment systems were developed to improve effluent water quality, however economic aspects should be considered. This study was thus carried out to investigate the application of date-palm fibers filtration as an efficient method to economically remove turbidity, phosphorus, organics in term of COD and helminth eggs of secondary domestic wastewater from an activated sludge treatment process. Column experiments were investigated to study the efficiency of date-palm fibers filters media used in this work for the removal of targeted matter under operational conditions (flow rate, filter depth, and diameter of the fibers). The results indicate that diameter of the fibers had the most significant factor affecting the removal of targeted matter. Pilot test results indicated that date-palm fibers filtration removed up to 54.9% of turbidity, 80.6% of COD, 57.7% of phosphorus and 98% of helminth eggs. Definitely, it could be concluded that the date-palm fibers could offer an appreciable economic and environmental potential, which should be in a position to effectively contribute to the valorisation of such as date-palm by-products for domestic or industrial wastewater treatment in southern of Tunisia.

Contents

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1. Introduction

The date palm *Phoenix dactylifera* L. is one of the most cultivated palms around the world. It is commonly found in the Afro-Asiatic dry-band, which stretches from North Africa to the Middle East [1,2]. It has a good tolerance to cold and dry-hot climates. In the Maghreb countries, and particularly in Tunisia, oases cover almost 40,000 ha and represent an original form of human development in very harsh climatic conditions [3,4]. Date palms have a fibrous structure, with four types of fibers: leaf fibers in the peduncle, baste fibers in the stem, wood fibers in the trunk and surface fibers around the trunk [5]. Surface fiber was chosen in this study as it seemed most suitable for exploitation. After annually trimming operations, enormous quantities of palm fiber wastes are thrown away, except in smaller scales for artisan products [6,7].

Among the various wastewater treatment processes, filtration is one of the effective and attractive processes to improve effluent water quality. Several filters media are eligible for such a purpose. Activated carbon (powdered or granular) is the most widely used adsorbent because it has excellent adsorption efficiency for organic compounds. However, the activated carbon is considered an expensive adsorbent, which makes the wastewater treatment a prohibitive cost step. Several studies have tried to replace the activated carbon with less expensive materials. Therefore, there is a growing interest in using low-cost, easily available materials for the adsorption of organics and nutriments (P, N...). Consequently, a number of low-cost, easily available materials are being studied for the removal of metals [8], dyes [9] and nutriments [10] from domestic or industrial wastewater at different operating conditions. Many studies have been conducted on the wastewater treatment or potable water treatment with depth filters, in which the packing material is an ensemble of fibers. Results have demonstrated that these filters are effective in removing organics [11–13], nutrients [14], particulate [15], and high metal species [16,17]. In this context, the date-palm fibers filters could be also a potential technology for nutriments removal (N, P) from wastewater in order to prevent such as eutrophication of the Medjerda River. This river is Tunisia's crucial waterway providing water to the country supply facilities. It is also vital for the people living near the river. Water from Medjerda is used for irrigation and is pivotal to agriculture of the region. Besides, one of the best options for Tunisian Agriculture is to use secondary domestic wastewater, filter and disinfect the effluent before it is reused in agriculture [18]. The final effluent must contain less than 1 helminth egg (HE/L) per liter and less than 1000 faecal coliforms/100 mL while still retaining nutrients and organic matter for their agronomic benefits. The application of such materials to the real conditions of domestic or industrial effluent treatment requires knowledge of their reactivity and the content of their adsorption sites to optimize the retention processes. Work to optimize the date-palm fibers filtration process is needed to develop the potential of this biofilm-based treatment in order to achieve strict discharge requirements at a reasonable cost.

The objective of the study reported herein was to investigate the application of date-palm fibers filters as porous medium for the tertiary domestic wastewater treatment. The removal of turbidity, organics in term of COD, nutriments (PO_4^{3-}), and parasites (helminth eggs) of secondary wastewater from an activated sludge treatment process by the later filters media was evaluated under various design, operational, and water quality conditions. The impacts of filter diameter, filter depth, and flow rate on removal of monitoring parameters were studied. Backwash and filtration runs were also evaluated.

Table 1
Design and operational conditions of date-palm fibers filtration

Factors (units)	Diameter of fibers (mm)	Filter depth (m)	Flow rate (mL/min)
High	0.8–1.2	0.36	72
Medium	0.5–0.8	0.24	36
Low	0.2–0.5	0.12	12

2. Materials and methods

2.1. Filter setup

A pilot-scale unit was set up at laboratory as shown in Fig. 1. A glass column (55 cm long, with an inner diameter of 6 cm) was packed with different bed heights (12, 24, and 36 cm) of filter media on a glass–wool support and was loaded with secondary effluent, which was domestic wastewater collected from an activated sludge treatment plant of the station of Medjez El Bab (North of Tunisia). Gravel was fitted at the outlet of the column in order to support medium and to prevent the loss of the adsorbent particles. The filter bed is backwashed with filtered wastewater.

2.2. Design and operational conditions

Three design and operational factors (filter diameter, filter depth, and flow rate), and three levels (high, medium, and low) of each factor, were investigated in this study. Design and operational conditions are presented in Table 1. Three filters with an internal diameter of 6 cm were set up, and each of them was loaded with different diameter ranges of date-palm fibers media (0.2–0.5, 0.5–0.8 and 0.8–1.2 mm). Fixed-bed up-flow filter media was fed by a peristaltic pump at a constant flow rate, ranging from 12 to 72 mL min^{-1}. Each filtration run lasted 36 h.

2.3. Materials-secondary effluents characteristics

The natural fibers used in this research are from the surface of the turn of *Phoenix dactylifera* L. date palm obtained from Mednine (southern of Tunisia). One type of date-palm surface fibers (DPSF),

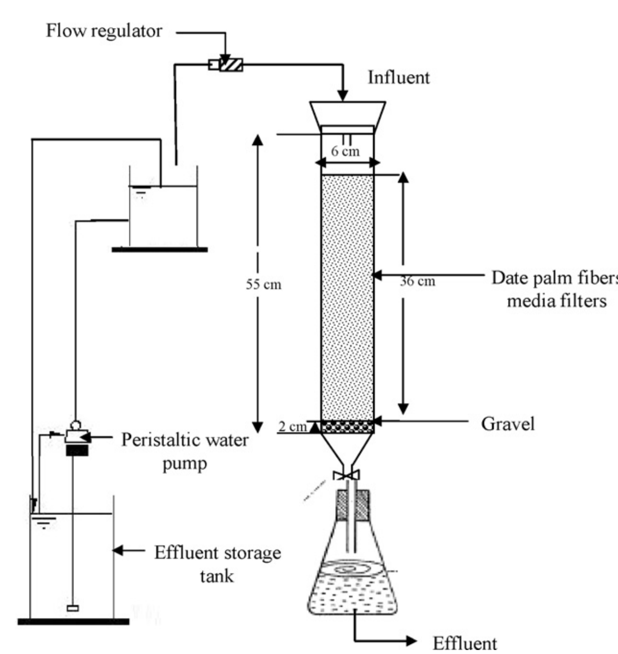

Fig. 1. Date-palm fibers filter setup.

Table 2
Mechanical properties of date-palm fibers

Palm types	Deglette-Nour
Fiber length (mm) (local name)	100
Condition	
Dry	
Tensile strength (MPa)	72.34 ± 18
Elongation (%)	8.7 ± 2.2
Modulus of elasticity (GPa)	3.15 ± 1.5
Wet	
Tensile strength (MPa)	74.34 ± 15
Elongation (%)	9.5 ± 2.5
Modulus of elasticity (GPa)	2.3 ± 2

corresponding to the principal palms: Deglette-Nour (local name), was tested. The date-palm surface fiber are naturally weaved, and are pulled out from trunk in the form of nearly rectangular mesh (length 300–500 mm, width 200–300 mm) formed with tree superposing layers. The layers are easily separated when immersed in water as individual fibers of diameter 0.2–0.8 mm. Table 2 presents the mechanical properties of individual date-palm surface fibers. The results show that wet fibers were marginally stronger than dry fibers [19–22].

Secondary domestic wastewater was obtained from an activated sludge treatment plant of the station of Medjez El Bab (north of Tunisia). Characteristics of the secondary domestic wastewater are given in Table 3.

2.4. Analytical procedure

Turbidity, organics in term of COD, nutriments (PO_4^{3-}), and parasites (helminth eggs) were monitored for both filter influent and effluent. Turbidity was measured by a portable turbidity meter (MERCK TURBIQUANT 1500 IR) calibrated with standard solutions (0.02, 10 and 1000 NTU). Organic matter in term of COD was determined in accordance with the closed reflux, colorimetric method. Molybdenum blue (ascorbic acid) absorptiometry was employed for the phosphorous analysis at 880 nm. Helminth eggs (Ascaris and Oxyure) enumeration was conducted with a clear 1-mL counting cell and a compound microscope (100×). All these methods of analysis are in conformity with the standard methods used for the Examination of Water and Wastewater [23] with the exception of helminth eggs concentration, which was determined according to a method published by the US EPA [24].

For each 36 h run, monitoring parameters were measured at run times of 2, 4, 8, 12, 16, 20, 24, 28, 32 and 36 h. Ten samples were taken for each filter. In this paper, the removal efficiency of each targeted parameter was the average value of these ten data points. Measurements were made in triplicates for the analysis of each monitoring parameters and data were recorded when the variations in two readings were less than 5% ($P < 0.05$).

Table 3
Characteristics of the secondary domestic wastewater

Parameters	Values
pH	7.4 ± 0.65
Temperature (°C)	18 ± 08
EC (μS/cm)	1773 ± 55
Turbidity (NTU)	27 ± 06
Suspended solids (mg/L)	25 ± 07
COD (mg/L)	105 ± 20
BOD_5 (mg/L)	37 ± 05
TKN-N (mg/L)	22.5 ± 07
PO_4^{3-}–P (mg/L)	1.9 ± 0.6
Helminth eggs (N/L)	15 ± 03

3. Results and discussion

3.1. Turbidity removal

The removal efficiencies under various design and operational conditions are summarized in Table 4. The highest turbidity removal efficiency was about 54.9 ± 1.70%, while the lowest was about 28.3 ± 0.35%. The results clearly indicate that the diameter of the fibers played an important role in turbidity removal: a smaller media diameter favoured the removal of turbidity. This observation was expected since a smaller media diameter corresponds to a smaller pore size. Consequently, a more solid matter could be strained by the filter media. Filter depth appeared to have a minor influence on turbidity removal compared with the effect of media diameter. Moreover, no clear relationship between filter depth and turbidity removal efficiency was found. Flow rate had a limited influence on turbidity removal: a higher filtration rate resulted in lower turbidity removal efficiency.

3.2. Organic removal (COD)

As shown in Table 5, the COD removal efficiencies ranged from 42.6 ± 0.15 to 80.6 ± 0.95%, depending on the design, operational and water quality conditions. Similar to turbidity removal, media diameter showed a substantial influence on COD removal: higher organic removal efficiency in term of COD corresponded with smaller media diameter. Compared with media diameter, filter depth and flow rate did not have a notable influence on the removal of organic in term of COD. The organic matter retained in the final effluent and accumulated onto date-palm fibers is friendly to the environment for agronomic benefits of the latter.

Table 4
Turbidity removal as a function of design and operational conditions

Filter depth (m)	Flow rate (mL/min)	Average removal efficiency (%)		
		0.2–0.5 mm media	0.5–0.8 mm media	0.8–1.2 mm media
0.12	12	48.7 ± 0.65	46.3 ± 0.45	32.2 ± 0.30
	36	47.3 ± 0.25	44.9 ± 0.20	31.3 ± 0.15
	72	46.6 ± 0.10	43.7 ± 0.10	28.2 ± 0.15
0.24	12	51.2 ± 1.15	48.3 ± 0.75	35.3 ± 0.55
	36	50.8 ± 0.85	47.2 ± 0.60	33.6 ± 0.35
	72	50.1 ± 0.35	47.1 ± 0.45	30.1 ± 0.15
0.36	12	54.9 ± 1.70	44.2 ± 1.20	32.5 ± 0.95
	36	51.7 ± 0.85	42.5 ± 0.70	29.9 ± 0.50
	72	48.6 ± 0.40	41.2 ± 0.45	28.3 ± 0.35

Table 5
Organics removal as a function of design and operational conditions

Filter depth (m)	Flow rate (mL/min)	Average removal efficiency (%)		
		0.2–0.5 mm media	0.5–0.8 mm media	0.8–1.2 mm media
0.12	12	77.1 ± 1.25	63.7 ± 0.75	43.1 ± 0.35
	36	74.2 ± 0.75	62.5 ± 0.25	42.6 ± 0.15
	72	78.2 ± 0.20	66.3 ± 0.65	44.2 ± 0.15
0.24	12	74.5 ± 1.15	64.5 ± 0.85	43.5 ± 0.65
	36	77.1 ± 0.35	67.1 ± 0.45	42.7 ± 0.35
	72	75.3 ± 0.80	62.8 ± 0.60	45.2 ± 0.50
0.36	12	80.6 ± 0.95	64.7 ± 0.65	47.2 ± 0.45
	36	78.9 ± 0.60	67.2 ± 0.15	45.3 ± 0.70
	72	77.4 ± 0.25	63.1 ± 0.20	44.2 ± 0.35

3.3. Phosphorus removal (PO_4^{3-})

The removal efficiencies of orthophosphates under various design and operational conditions are summarized in Table 6. The highest orthophosphates removal efficiency was about 57.7 ± 1.25%, while the lowest was about 8.2 ± 0.15%. The results clearly indicate that the media diameter played an important role in phosphorus removal: a smaller media diameter favoured the removal of phosphorus. In addition, the mass of the filter media forming the homogenous fixed bed is proportional to the bed depth and as a result the number of sorption sites increases with the increase in bed depth, leading to a larger sorption capacity of the reactor. The flow rate dependence can be accounted for by the fact that for lower value of flow rate, the contact time is longer, and hence the interaction between phosphorus and the filter media is also greater. This leads to higher rate of phosphorus sorption. On the other hand, for higher flow rate, the contact time is shorter and the phosphorus sorption is also lower, due to lesser interaction.

3.4. Helminth eggs removal

The detailed information of helminth eggs removal is presented in Fig. 2. The results showed an average helminth eggs removal efficiency of 98 ± 0.70% for filter depth = 0.36 cm and flow rate = 72 mL/min. Similar to turbidity removal, media diameter showed a substantial influence on helminth eggs removal: higher helminth eggs removal efficiency correlated with a smaller media diameter. In addition, the helminth eggs removal rate appears to increase with flow rate. We presume that the flow rate dependence can be accounted for by the fact that for higher value of flow rate, the filling of the fiber filter is faster. As a result, high filtration rates could enhance retention of helminth eggs through the filter media, thus increasing the helminth eggs removal.

To achieve the necessary goal of less than 1 helminth eggs (HE/L) per liter, an additional treatment step is necessary. Because of the extremely low doses of helminth eggs that cause infection, and the resistance of these micro-organisms to traditional methods of disinfection, it is essential to find a final disinfection step that is required to remove faecal coliforms from secondary effluents.

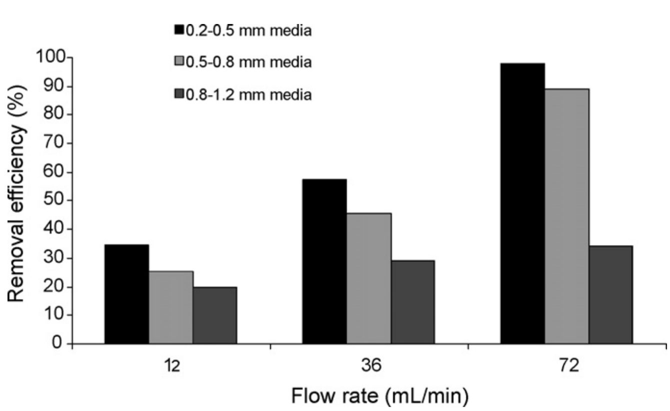

Fig. 2. Helminth eggs removal as a function of design and operational conditions (filter depth = 0.36 m).

3.5. Backwashing

Effective backwash is essential to the successful long-term operation of filters. In this study, filtered water was used for backwash, and the backwash was completed when backwash water turbidity reached 9 NTU.

The relative backwash water usages are shown in Fig. 3. In this study, the backwash water volumes were about 1.38–3.31 L (while water productions were 17.28, 51.84, 103.68 L for flow rates at 12, 36, 72 mL/min, respectively, after a 24 h run) for 0.2–0.5 mm media diameter, while the backwash water volumes were about 0.86–2.17 L (while water productions were 17.28, 51.84, 103.68 L for flow rates at 12, 36, 72 mL/min, respectively, after a 24 h run) for 0.8–1.2 mm media diameter. So, smaller media filters might require more backwash water usage than larger media filters. Compared with traditional granular filters, the date-palm fibers filter used much lower backwash water flow rate which reduces the size of the backwash pump and power requirement.

4. Discussion

4.1. Filtration mechanisms

Date-palm surface fiber filter is an assembly of fibers that are randomly laid perpendicular to the wastewater flow. The fiber has diameters in the range from 0.2 to 1.2 mm, and forms a network

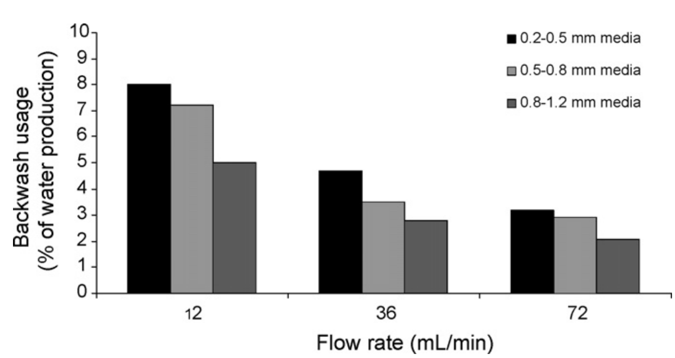

Fig. 3. Backwash usage (% of water production) (filter depth = 0.36 m).

Table 6
Phosphorus removal as a function of design and operational conditions

Filter depth (m)	Flow rate (mL/min)	Average removal efficiency (%)		
		0.2–0.5 mm media	0.5–0.8 mm media	0.8–1.2 mm media
0.12	12	38.4 ± 0.45	30.5 ± 0.65	17.7 ± 0.25
	36	33.3 ± 0.25	22.9 ± 0.40	11.5 ± 0.15
	72	25.6 ± 0.20	18.4 ± 0.25	08.2 ± 0.15
0.24	12	50.1 ± 0.75	37.2 ± 0.65	23.7 ± 0.40
	36	44.3 ± 0.60	29.1 ± 0.45	18.5 ± 0.60
	72	32.8 ± 0.25	22.8 ± 0.15	14.1 ± 0.35
0.36	12	57.7 ± 1.25	45.1 ± 0.95	31.2 ± 0.75
	36	48.3 ± 0.85	36.5 ± 0.50	29.9 ± 0.30
	72	37.5 ± 0.45	28.2 ± 0.25	28.3 ± 0.35

with wide range of distribution in pore size. This kind of structure provides both physical barrier and great adsorbing capacity due to its large surface area, resulting in high capture efficiency for suspended particles and other contaminants in wastewater.

As described in the literature [25], there may be four mechanisms governing the filtration performance of date-palm surface fiber in the wastewater treatment process, namely: impaction, interception, diffusion and adsorption. Impaction and interception are the dominant filtration mechanisms of blocking large particles. Diffusion plays important roles in capturing small particles. The reduction of organics in terms of COD may be governed mainly by adsorption, while that of the PO_4^{3-}–P should be attributed mainly to electrostatic interaction and accumulation process. Particle destabilization processes, e.g., coagulation resulting from the Brownian motion, should be considered to enhance the removal performance of date-palm fibers filters. Small colloid particles and some high molecular-weight organic compounds which already deposited on date-palm surface fiber are flocculated or co-precipitated. Therefore, all above mechanisms become more effective.

4.2. Comparison with sand bed filters

To date, sand bed filters have been used as a low-cost effective alternative to conventional septic tank/soil adsorption systems for domestic waste [26,27]. The performance of sand bed filters is influenced by numerous factors, which include bio-augmentation, media depth, grain size distribution, mineral composition of media, pre-treatment, wastewater composition and nutrient concentration, hydraulic and organic loading rates, temperature and dosing techniques [28]. In comparison to traditional granular media filters (e.g., sand), because of its elasticity, the date-palm fibers filters may allows higher filtration rate, lower head loss, and longer filtration run time. Because of low density of these materials, the date-palm fibers filters can be backwashed at a much lower backwash water flow rate than the conventional sand filter. The low backwash water flow rate reduces the size of backwash water pump and the power requirement. Also, the date-palm fibers that adsorbed and accumulated organics and nutrients (phosphorus) can be a friendly product to the environment, as it does not require further treatment for regeneration because of its potential application to acid soils fertilization in arid climate.

4.3. The prospect of using date-palm fibers materials

Typical removal methods for high concentration of phosphorus consist of biological treatments such as the conventional activated-sludge process, chemical treatments, such as precipitation with Al, Fe and Ca components, or a combination of both treatments. However, in the case of a low concentration of phosphorus, bio treatment and precipitation are not effective. Fixed-bed processes using adsorption methods are recommended as the most effective removal processes for low concentrations [29–31].

The results of PO_4^{3-} concentration analysis in liquid phase show that the amount of PO_4^{3-} stilled in the backwash water is about 10 ± 02% for flow rate at 12 mL/min, for 0.2–0.5 mm media diameter and after a 24 h run. These results indicate that both accumulation and retention of phosphorus onto date-palm fibers is higher (90 ± 02%). The adsorption of PO_4^{3-} onto date-palm fibers may not be completely reversible and the bonding between the sample particles and sorbed PO_4^{3-} is likely strong. Also, for the same experimental condition, analysis in the backwash water shows that the number of helminth eggs was 2 HE/L. Therefore, the desorbability of helminth eggs is about 13.60 ± 03%. These results indicate also that it is relatively difficult for the adsorbed helminth eggs to be desorbed from date-palm fibers. Consequently, the date-palm fibers that adsorbed, accumulated organic and nutrient products such as phosphorus may be a friendly material to the environment, as it does not require further treatment for regeneration because of its potential application to acid soils fertilization in arid climate such as southern of Tunisia.

Date-palm fibers are a natural, inexpensive, and environmental friendly material available in enormous quantities thrown away as wastes after annually trimming operations, which occupies large areas in southern of Tunisia. Because of their low-cost, these materials can be profitably used as alternatives or complements to the more commonly used methods for effluent treatment. The date-palm fibers filter could be a potential technology for tertiary domestic wastewater treatment (at least at the proximity of the effluent treatment plant) in order to remove restrictions on water reuse in arid and semi-arid climate of Tunisia.

5. Conclusions

Based on the above results, the following conclusions can be drawn:

- Pilot test results indicated that date-palm fibers filtration removed up to 54.9 ± 1.70% of turbidity, 80.6 ± 0.95% of COD, 57.7 ± 1.25% of phosphorus and 98 ± 0.70% of helminth eggs.
- Diameter of the fibers was the most significant factor affecting the treatment of secondary wastewater by date-palm fibers filtration.
- Filtration rate impacted turbidity and phosphorus removal: increasing filtration rate reduced removal efficiencies to some degree.
- Backwash water usage for date-palm fibers filtration was less than traditional sand and anthracite filters. Smaller media filters might require more backwash water usage than larger media filters.

Based on the study, date-palm fibers filtration could be a potential technology for tertiary wastewater treatment as it provides a "green engineering solution". Because the removal efficiencies did not meet the requirement outlined under the Tunisian Norms for wastewater treatment, particle destabilization processes, e.g., coagulation should be considered to enhance the removal performance of date-palm fibers filtration. Further study is also needed on the use of the date-palm fibers filtration as the pre-treatment process for chlorine, UV, ozone, and other disinfection technologies.

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