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Nitrogen and phosphorous removal from aerated lagoon effluent using horizontal roughing filter (HRF)

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ABSTRACT

Traditionally, aerated lagoons are not reliable wastewater treatment systems to eliminate nutrient contents of municipal wastewater. This study aimed to enhance the aerated lagoon effluent quality by applying a simple filtration system. Removal of nitrogen and phosphorous from aerated lagoon effluent using horizontal roughing filter (HRF) was investigated. Also, the "1/3–2/3 theory" was applied to predict the TSS concentration of HRF effluent. An experimental setup of HRF was used to receive the continuous effluent from wastewater treatment plant. HRF was operated at three consecutive filtration rates, including 0.5, 1 and 1.5 $m^3 m^{-2} h^{-1}$. At the first filtration rate (0.5 $m^3 m^{-2} h^{-1}$), the removal efficiencies of total Kjeldahl nitrogen, total phosphorous, TSS, and COD were reported 50, 54, 63, and 68%, respectively. Decreasing the removal efficiency was occurred during raising the filtration rate ($p < 0.05$). Applying the "1/3–2/3 theory" revealed the significant correlation between predicted and measured TSS values. The capacity of HRF to retain nitrogen, phosphorous, and COD during the filtration runs was 24.3, 10.1, and 435.4 $g m^{-3} d^{-1}$, respectively. HRF can be applied as an appropriate alternative for tertiary treatment of the aerated lagoon effluent.

Keywords: Aerated lagoon; Effluent; Horizontal roughing filter; Kjeldahl nitrogen; Suspended solids

1. Introduction

The aerated lagoons, unless modified for nitrification, are not efficient systems for nitrogen and phosphorous removal and do not have comparable reliability as facultative ponds. High fluctuations in pH and alkalinity during the diurnal periods which can alter the removal efficiencies of NH_4-nitrogen and phosphorous in facultative ponds do not occur in aerated lagoons [1]. Furthermore, aerated lagoons are not

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the appropriate systems to produce the effluents with acceptable suspended solids (TSS) concentrations [2].

During the last decades, various investigations have been conducted to evaluate the appropriate and economic alternatives for improving the quality of aerated lagoon effluent [3–5]. The intermittent sand filter (ISF) is denoted as an acceptable alternative for aerated lagoon effluent treatment. But, usually the operation of ISF incorporates some considerations, such as need for regular maintenance, land requirement, filter media availability, odor problems, and high sensitivity to the temperatures [6].

Among the other available systems that have been employed to upgrade the aerated lagoon effluent, the two-stage filtration (TSF) units are the noticeable examples. TSFs, in well-operated conditions, have the capability to maintain the phosphorus content of the effluent around 0.02 mg L^{-1} [7,8].

Roughing filters are mainly used as water pretreatment options prior to the slow sand filters, especially when the treatment facilities are subjected to high turbid surface waters or run-off events [9,10]. Horizontal roughing filter (HRF) can be defined as an extended free-surface trough usually comprised with three subsequent flow-through cells known as compartments. The compartments are filled with the gravel media, which contributes a decreasing size arrangement from the beginning to the end. The crushed river rocks can be used as gravel media. The range of gravel size has been often from 2 to 20 mm. Usually, the filtration rates are adjusted in less than 1.5 $m^3 m^{-2} h^{-1}$ [11,12]. The gravel bed can provide a laminar hydraulic regime during the filtration rates less than 3 $m^3 m^{-2} h^{-1}$ [11]. Consequently, the gravel bed can be compared with the plats in the plate settlers. During the filtration process, suspended particles are trapped on the surface of gravels. The filter cleaning is performed by water flushing, which cause the gravels to agitate and dislodge the attached sludge [13,14].

Some prediction models have been applied to determine the HRF behavior during the filtration process. Usually, TSS is served as a surrogate parameter in these models. Investigating the HRF efficiency using the Wegelin criteria known as "1/3–2/3" theory has been well approved. Also, other approaches such as neuro-genetic models represent acceptable results but most of them may be required the complicated prerequisites [15].

This study examined the removal of nitrogen and phosphorus from aerated lagoon effluent using an experimental setup of HRF. Also, the removal of suspended solids and COD were considered. Then, the Wegelin theory known as "1/3–2/3" was applied as a model to describe the performance of HRF via predicting the effluent concentration of suspended solids. Evaluating the HRF as a tertiary treatment unit for the effluent of aerated lagoon was the main objective of the experiment.

2. Materials and methods

2.1. Study area

Qom wastewater treatment plant (WWTP) has been located in the northeastern part of the city, beside the Qomroud River. Qom WWTP is an aerated lagoon system consisting of two parallel sets of cells. Each set of cells includes four basins (lagoons). The dimension of each basin is 100 m (length) × 80 m (width) × 4 m (depth).

Basins have been connected to each other in series. Both parallel sets of basins were in use during the study period, but if necessary, the WWTP can be operated by each set of basins alone. Except the final basin of each lagoon series, the previous lagoons have been equipped with mechanical floating aerators. The final effluent is used for flooding irrigation. The excess effluent and also the irrigation drainage are discharged to the Qomroud River.

The surplus effluent is discharged to the river under the gravity head and the effluent that is used for irrigation is supplied via a pumping station situated beside the final effluent channel. The station is comprised of two parallel pumps, which work intermittently. Consequently, the effluent discharge was continuously flowed during the study period. The main drawbacks in Qom WWTP are high concentration of suspended solids, high level of turbidity, and elevated content of organics in the final effluent. Table 1 shows the main parameters of the Qom WWTP effluent during the study period, from January to April 2012.

2.2. Experimental setup

An experimental setup was connected to the discharge pipe of the pumping station. As illustrated in Fig. 1, the experimental setup was a HRF, which comprised of three attached compartments with identical circular cross-sections with 0.5 m, diameter. The overall length was 4 m that the inlet and outlet zones were also included. River gravels served as the filtration media. Compartments have been separated from each other and also from the inlet and outlet zones via four perforated walls. The number and size of holes on the walls were 2 hole cm^{-2} and 3 mm, respectively.

Table 1
Characteristics of the influent feeding the pilot-scale (effluent of Qom WWTP)

		Hydraulic loading rate ($m^3\ m^{-2}\ h^{-1}$)		
Parameter*	Unit	0.5	1	1.5
Temperature	℃	7.2 ± 2.6**	9.7 ± 2.9	16.3 ± 3.2
pH	–	7.2 ± 1.4	7.6 ± 0.14	7.8 ± 0.6
Suspended solids	$mg\ L^{-1}$	99.4 ± 9.2	85.3 ± 6.6	98.7 ± 10
Total Kjeldahl nitrogen	$mg\ L^{-1}$ as NH_3	15.4 ± 1.3	14.3 ± 1.6	14.8 ± 0.7
Total phosphorous	$mg\ L^{-1}$ as P	6.0 ± 0.3	5.7 ± 0.8	6.7 ± 0.5
COD	$mg\ L^{-1}$	202 ± 15.6	194 ± 11.9	184.6 ± 11.3

*Number of grab samples: 74 (duplicate analysis).
**Average ± Standard deviation.

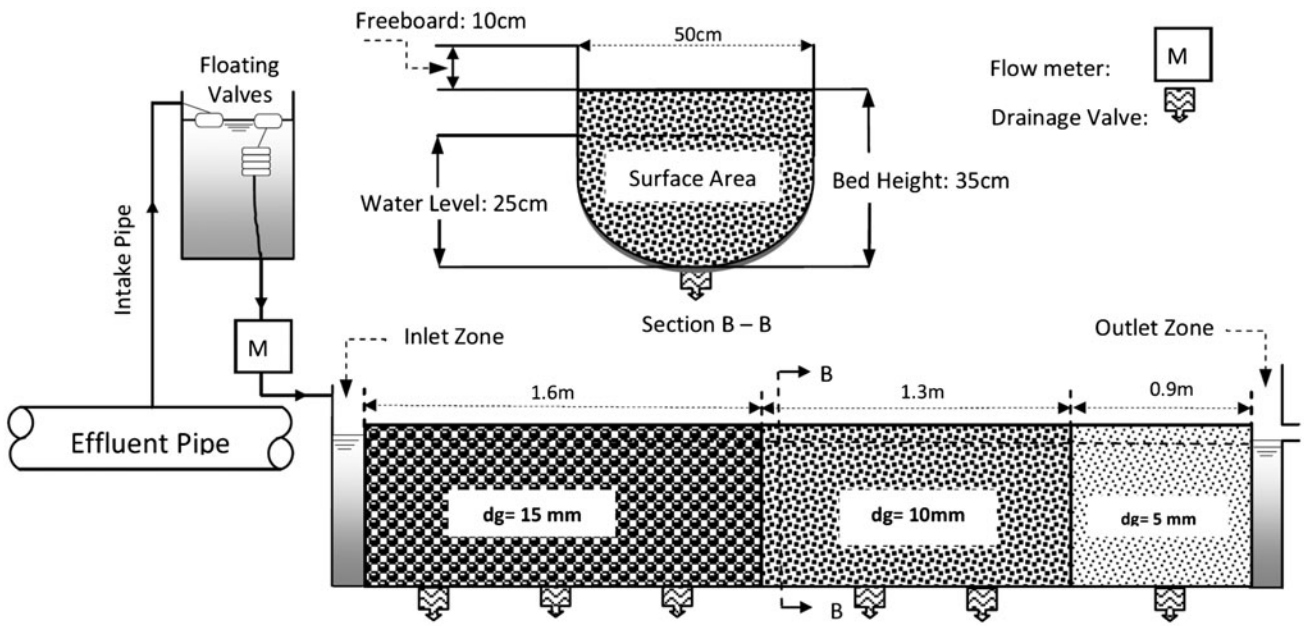

Fig. 1. Schematic layout and details of HRF pilot system.

The surface area is defined as the cross-sectional wet surface of gravel bed, which is exposed to the horizontal flow of water during the filter operation. So, by applying Eq. (1), the filtration rate (V_f) can be computed as follows:

$$V_f = \frac{Q_{in}}{S} \quad (1)$$

where, Q_{in} is the inlet flow rate ($m^3\,h^{-1}$) which is determined with a flow meter installed on the HRF feeding pipe. S is the surface area (m^2).

To avoid the short-circuits and also to prevent the algal growth on the horizontal surface of media, the water table was adjusted about 10 cm beneath the media surface based on the recommends of Collins et al. [16]. So, the height of wet media from the bottom of each compartment was 25 cm (section B–B of Fig. 1). However, during the filtration runs, clogging was developed and the upper dry media were submerged gradually during the head loss increasing. Appearance of water on the horizontal surface of the media was the sign of over-clogging, which was initiating from the beginning of the first compartment adjacent to the inlet zone (Fig. 1).

Operating the experimental setup after over-clogging events could be creating a short-circuit flow over the filter media. So, to interrupt the filtration, performing a hydraulic washing (flushing) was inevitable during this event. As can be inferred from Fig. 1, the hydraulic flushing was performed by entering the hydraulic rates about 10–30 times more than the ordinary operation rate and simultaneously, opening the six flushing valves in the filter bottom for disposing the sediments [17].

The flushing system was adjusted to support the hydraulic rates around 30 $m^3 m^{-2} h^{-1}$ as proposed by Collins et al. [16]. To improve the effectiveness of flushing, the compartment walls were designed according to a curved pattern. The aim was to obtain an appropriate slop during the draining disposal which was based on the experiments of Torabian and Fazeli [18] and can be identified from the section B–B of Fig. 1.

An elevation tank with the volume of 0.22 m^3 was installed beside the experimental setup. The tank was equipped with inlet floating valve, outlet floating gate, mixer and drainage valve, and was receiving the effluent of WWTP via a or an intake pipe. After passing through the flow meter, the effluent then was delivering to the inlet zone of HRF.

The crushed gravel was locally available, which was considered as a low-cost media with the specific surface area of approximately 90 $m^3 m^{-2}$. Table 2 shows the operational design criteria of HRF obtained from wegelin [11].

2.3. Materials, sampling, and analytical methods

The gravels were prepared from the riverbanks of Qomroud. Then, gravels were washed, dried, and separated to required effective sizes as denoted in Table 2. The gravel classification was performed using the standard ASTM laboratory sieves.

Duplicated samples were taken simultaneously from the inlet and outlet zone of HRF. Total 80 samples (duplicated) were obtained during 80 d at four months from 24 January to 12 April 2012.

Table 2
Operational design criteria for the HRF pilot system

Parameter	Unit	Compartment 1	2	3	Total
Wet surface area	m^2	0.1	0.1	0.1	–
Height	m	0.45	0.45	0.45	–
Length	m	1.6	1.3	0.9	3.8
Volume	m^3	0.16	0.13	0.09	0.38
Bed weight	kg	424	345	239	1,008
Gravel effective size	mm	6.8	5	3.2	–
Drainage valve	number	3	2	1	–
Slop*	%	1	1	1	
Bed height	m	35	35	35	–
Submerged height	m	25	25	25	–

*From inlet toward outlet.

Materials used in laboratory analysis prepared from Merck Company (Merck®, Germany). Samples were analyzed according to APHA (2007) for suspended solids (SS) (method; 2540 D), COD [(method; 5220 D) and spectrophotometer (Model DR-4000), Hatch® Company, USA], total Kjeldahl nitrogen (TKN) (method; 4500-N B), and total phosphorous (TP) (method; 4500-P C) [19].

2.4. Modeling the suspended solids concentration in the effluent of HRF

Among the various approaches which have been developed to model the depth filtration relied on horizontal flow modes, the "1/3–2/3 theory" of Wegelin is a simple approach for gravel filters [17].

When a particle in the water penetrates through a medium filled up with gravel, there is the same possibility of passing the particle either through left or right or to deposit on the surface of the gravel. Consequently, the probability of the achievement of deposition on the gravel surface and escaping from it is 1/3 and 2/3. This idea is the basis of the Weglin's 1/3–2/3 theory.

Thus, as the filtration run time continues the impact of multi-layers (compartments) of the HRF provide more opportunities to separate the particles. The "1/3–2/3 theory" has been obtained to establish the approaches for predicting the removal efficiency in various kinds of roughing filter. According to the filter theories and the Fick's law, the efficiency of filter is defined by the filter coefficient using a differential equation as follows (Eq. (2)):

$$\frac{\mathrm{d}c}{\mathrm{d}x} = -\lambda c \tag{2}$$

where, c, x, and λ are the solid concentration (mg L^{-1}), filter depth (m), and filter coefficient, respectively. It can be indentified from Eq. (2) that the initial concentration of particle in the water indicates the rate of particle removal by HRF.

The length of filter determines the number of conceptual parallel plates (the randomly curved surfaces of gravels, in reality), which can be denoted as multistage reactors. So, the overall elimination efficiency of a HRF system is based on the data obtained from these small filters. The final solids concentration after penetrating through the length of Δx can be represented as follows (Eq. (3)):

$$C_e = \sum C_0 \exp(-\lambda_i \Delta x) \tag{3}$$

where, Δx is the depth (known as "length" for HRF) of filter cells (or compartments) and λ_i is the coefficient of each filter cell. C_0 and C_e are the suspended solid concentrations in the inlet and outlet zones, respectively. The "$\exp(-\lambda_i \Delta x)$", in Eq. (3), is identified as the filter cell efficiency (FCE) and can be denoted with E_i.

According to the "1/3–2/3 theory", it can be supposed that the combinations of FCEs (E_i) are represented as the compartment efficiency (E). Consequently, the final TSS concentration, in the effluent of an HRF system comprising n compartments, can be estimated by the following equation (Eq. (4)):

$$C_e = C_0 \times E_1 \times E_2 \times E_3 \times E_4 \times \dots E_n \tag{4}$$

where, E_n is defined as the filter efficiency assigned to compartment n. Furthermore, the values of E_n, in Eq. (4), can be indicated through respective nomograms or tables which have been proposed by Wegelin [17].

2.5. Data management

Variables were compared with a one-way ANOVA and a Tucky Test. All statistical analyses were performed using SPPS version 18.5 (SPSS Inc., Chicago, IL, USA). Microsoft Excel 2007 was used for calculations and graphs depiction.

3. Results and discussion

The purpose of the study was to evaluate the HRF performance for nutrients and solids removal of aerated lagoon effluent. The HRF ability for reducing TP, TKN, SS, and COD during three filtration rates was investigated. The "1/3–2/3 theory" of Wegelin [17] was served as a model for predicting the TSS values of HRF effluent and then, modeled results were compared with observed data. The relationship between head loss and removal of measured parameters during the first filtration rate (0.5 m h^{-1}) was also considered.

3.1. SS, TP, TKN, and COD removal

Table 3 shows the SS, TP, TKN, and COD values from aerated lagoon effluent, which was entered in the HRF during the study period. There was no significant difference and also, there was no obvious increasing or decreasing trend in measured values of system inflow during the three filter runs ($p = 0.38$). The results listed in Table 3 show the statistical summary of values measured from HRF outlet samples. As inferred from Table 3, the difference between values, attributed to each parameter in an outlet is significant in three filtration rates ($p < 0.05$).

During a pilot experiment from four months from March to August on effluent of a facultative pond with a horizontal rock filter, it was found that 77.3% removal of TSS can be occurred [20].

Dastanaie et al. have reported 89.7% removal of TSS with an HRF installed beside a riverbank from February to September 2006 [21].

Results obtained from the first filtration rate represent a good compliance with the national standard considerations [22]. But for other filtration rates, except for TSS and COD, the other parameters measured in HRF effluent could not meet the national standard. Therefore, if the nutrients be intended as constituents that should be controlled by HRF,

Table 3
Process performance summary for the HRF during three V_f (0.5, 1 and 1.5 m^3 m^{-2} h^{-1})

V_f^* (m^3 m^{-2} h^{-1})		TSS (mg L^{-1})	TKN (mg N L^{-1})	TP (mg P L^{-1})	COD (mg L^{-1})
0.5	Average	36.9	7.7	2.8	64.4
	SD	32.5	1.8	0.9	46.2
	Min	8.0	5.5	1.9	21.0
	Max	100.0	11.0	4.9	183.0
1	Average	34.4	7.9	2.7	107.0
	SD	12.0	2.8	0.7	36.6
	Min	21.0	2.8	1.5	62.0
	Max	63.0	12.9	4.0	174.0
1.5	Average	46.7	8.5	3.6	113.8
	SD	15.4	1.4	0.7	35.5
	Min	28.0	6.5	2.9	67.0
	Max	80.0	11.2	4.9	175.0

*V_f: Hydraulic filtration rate.

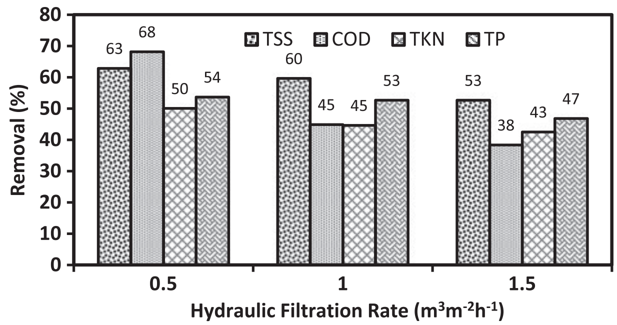

Fig. 2. Removal efficiencies of TSS, COD, TKN, and TP in three hydraulic filtration rates (0.5, 1, and 1.5 $m^3\ m^{-2}\ h^{-1}$).

adjusting the filtration rate around 0.5 $m^3\ m^{-2}\ h^{-1}$ is proposed.

Fig. 2 shows the average percentage removal obtained for the filtration rates below 1.5 $m\ h^{-1}$ for TSS, COD, TKN, and TP, which can be concluded that the removal efficiencies are decreased with the increasing of V_f.

As shown in Fig. 2, during the first filtration rate (V_f 0.5 $m^3\ m^{-2}\ h^{-1}$), the average removal of TSS, COD, TKN, and TP was 63, 68, 50, and 54%, respectively. In the third filtration rate (V_f 1.5 $m^3\ m^{-2}\ h^{-1}$) values were 53, 38, 43, and 47%, respectively. Nkwonta reported 89% removal of TSS value achieved by HRF at a filtration rate of 0.75 $m\ h^{-1}$ [23]. Rooklidg and Ketchum have found 95% of TSS removal by a pilot-scale HRF based on crushed dolomite gravel as media [14].

Al-Saed et al. reported 80.5% removal of COD by a horizontal rock filter which received the effluent of a facultative pond [20]. It can be observed from Fig. 2 that increasing the V_f from 0.5 to 1 $m^3\ m^{-2}\ h^{-1}$ tend to 30% decreasing in COD removal efficiency that may be due to reducing the detention time in higher filtration rates [11]. Lower detention time tends to lower the opportunity of solid deposition inside the filter bed. Fig. 3 shows the TSS, TKN, TP, and COD values measured in double samples taken from the inlet and outlet zones of HRF and in different filtration rates.

As revealed in Fig. 3, minimum values of TSS, TKN, TP, and COD were achieved after almost 20 d from beginning of filtration rates, which also represents a sustainable condition until the end of filtration run. Gradually, decreasing trend of outlet values is observed in three filtration rates (Fig. 3), which supports those of Wegelin [11]. Ahsan found that the roughing filters can remove clay particles more effectively when the filter was ripened with algal cells after several weeks [24].

To avoid complexity during the operation, HRF systems are not equipped with aeration apparatuses. So, ammonia removal did not occur in the HRF [25] and the portion of TKN which was removed may be assigned to the organic nitrogen.

3.2. Predicting the effluent TSS of HRF with the E_n-value concept

By using the table and graphical nomogram developed by Wegelin [17], the values of E_n attributed to each HRF compartments were obtained by Eq. (4) and have been depicted in Table 4. As shown in Table 4, the total E-values belonged to each filtration rate is calculated by multiplying three E_n-values of respective filtration rate.

Then, the predicted TSS final concentrations of HRF at three filtration rates are illustrated in Fig. 4. As can be inferred from Fig. 4, the values of predicted suspended solids in the filtration rate of 0.5 $m\ h^{-1}$ are much lower than the observed (measured) values.

These differences may be due to the lack of further solid deposition in the first filter run, which tends to decrease the filtration performance [16,26]. In the next two filtration rates the values of predicted TSS in the filter effluent were increased and so achieved a noticeable compliance with the observed results Fig. 4.

The results have also been observed in the Ochieng et al. experiments [27,28]. Nkwonta have reported the total E-value of 0.026 for a filtration rate of 0.75 $m\ h^{-1}$ with the same three compartments and the overall length of 1.35 m [23].

3.3. Organic and nutrient loads

It can be determined from the average loading rates (LR) given in Table 5 that the filter retained the TKN by 24.3 $g\ m^{-3}\ d^{-1}$ in the first filtration rate (V_f = 0.5 $m^3\ m^{-2}\ h^{-1}$) and there was a direct relationship between the filtration rate and the loading rate (R^2 = 0.98). Zhao et al. [29] reported the load of 1.07 kg COD $m^{-3}\ d^{-1}$ by a biological aerated filter for oil field wastewater treatment which was noticeably more than our findings. It may be due to the effect of aeration which enhances the process efficiency.

Our results were in agreement with those of Stephenson et al's [30] which reported that 0.01—0.07 kg TKN $m^{-3}\ d^{-1}$ was loaded by a biological aerated filter during the leachate treatment.

The relationship between added and retained phosphorous during the first filtration rate (V_f = 0.5 $m^3\ m^{-2}\ h^{-1}$) was also obtained, and the result was

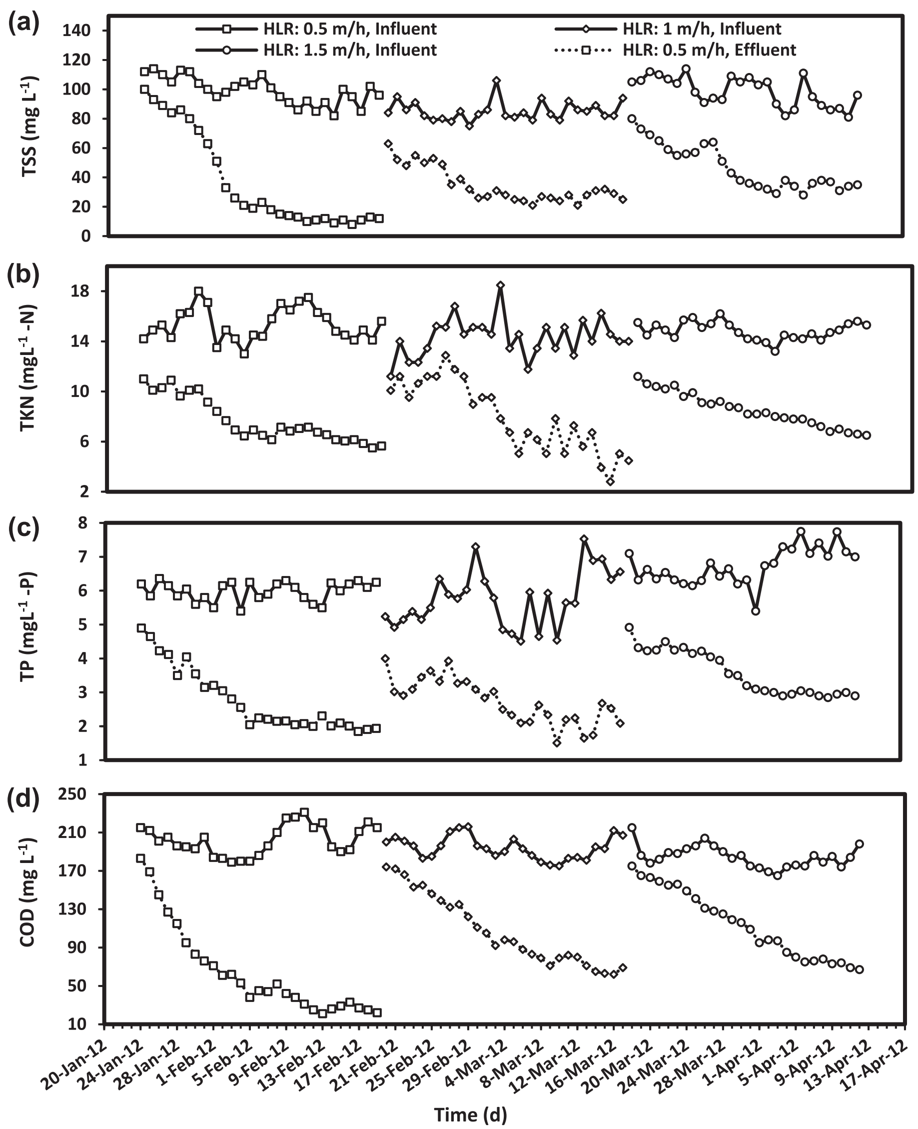

Fig. 3. Values of (a) SS, (b) TKN, (c) TP, and (d) COD from influent and effluent flows of HRF during three subsequent V_f (0.5, 1, and 1.5 $m^3\,m^{-2}\,h^{-1}$).

depicted in Fig. 5. Determining the similar models for the next filtration rates (1 and 1.5 $m^3\,m^{-2}\,h^{-1}$) are not precise and even applicable because the three filtration rates were not investigated in separated HRF systems. So, although the washing program was done in the end of each run, but except for the first run, the second and third filtration rates may be affected by the retained phosphorous deposited from the previous operation.

As inferred from Fig. 5 a correlation between the cumulative amounts of added and retained phosphorous ($R^2 = 0.993$) is observed, which can be represented with following equation (Eq. (5)):

$$\left[P\,retained\left(g\ TP\ tonne^{-1}\ gravel\right)\right] = 1.367 \times \left[P\,added\left(g\ TP\ tonne^{-1}\ gravel\right)\right]^{0.806} \tag{5}$$

Shilton et al. [31] investigated the phosphorous removal by an "active" slag filter during a decade of full-scale experiment. Their analysis depicted a clear linear trend for just over five years up to approximately 1.7 kg TP $tone^{-1}$ slag of "phosphorous added", which corresponds to a phosphorous retained ratio of 1.23 kg TP $tone^{-1}$ slag. Also, according to the results illustrated by Shilton et al. [31] the retained phosphorous after the first year of filter operation was up to

Table 4
E-values of various filtration rates attributed to each compartment

V_f^* ($m^3\ m^{-2}\ h^{-1}$)	d_g^{**} (mm)	L_f^{***} (m)	E_n-value (%)	Total *E*-value (December)
0.5	5	1	15.2	0.0146
	10	1.3	28.73	
	15	1.6	33.46	
1	5	1	39.9	0.131
	10	1.3	54.62	
	15	1.6	59.98	
1.5	5	1	59	0.333
	10	1.3	72.48	
	15	1.6	77.9	

*Filtration rate.
**Gravel size.
***Compartment filter length.

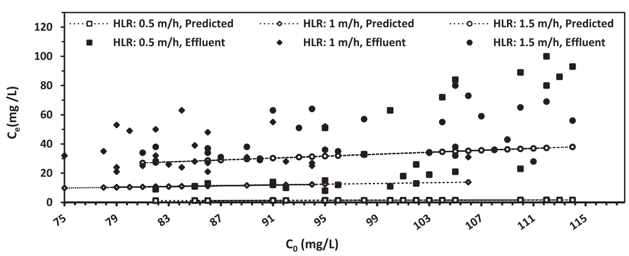

Fig. 4. Comparison of observed vs. predicted TSS in effluent for various filtration rates.

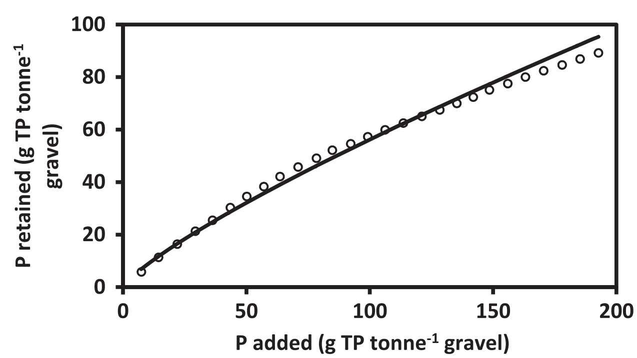

Fig. 5. The relationship between added and retained phosphorous during the first filtration rate ($V_f = 0.5\ m^3\ m^{-2}\ h^{-1}$).

Table 5
Obtained amount of LR during three filtration runs

	V_f ($m^3 m^{-2} h^{-1}$)		
LR ($g\ m^{-3} d^{-1}$)	0.5	1	1.5
TKN	24.3	40.3	59.8
TP	10.1	19.1	29.8
COD	435.4	550.2	670.8

0.2 kg TP tone^{-1}, slag which was comparable with the results of our study [31].

4. Conclusion

HRF can be applied as a simple and low-cost approach to improve the quality of turbid water sources. The simplicity of operation, reliability, and using the available masonry materials for construction are some reasons for considering the HRF as an appropriate alternative for water pretreatment. Evaluating the nutrient removal from effluent of aerated lagoon by using the HRF system was aimed in this study. Also, modeling the behavior of HRF system in TSS removal during the three filtration runs was considered. The following statements can be concluded from the study:

(1) During the first filtration rate ($V_f = 0.5\ m^3\ m^{-2}\ h^{-1}$), the average removal of TSS, COD, TKN, and TP was 63, 68, 50, and 54%, respectively.
(2) Increasing the filtration rate from 0.5 to 1.5 $m^3\ m^{-2}\ h^{-1}$ had the reducing effect on the removal efficiencies of measured parameters, which indicated the importance of filter operation in lower hydraulic rates.
(3) Applying the "1/3–2/3 filter theory" based on the TSS data obtained from the HRF effluent represented the better correlation between predicted and measured results at higher filtration rates.
(4) The final effluent of first filtration rate ($V_f = 0.5\ m^3\ m^{-2}\ h^{-1}$) contained 36.9 ± 32.5, 7.7

± 1.8, 2.8 ± 0.9, and 64.4 ± 46.2 of TSS, TKN, TP, and COD, respectively, which are under the standard considerations indicated by ISIRI for effluent discharge.

(5) The filtration rates more than $0.5\,m^3\,m^{-2}\,h^{-1}$ did not meet the national standard limitations. Therefore, adjusting the filtration rates around $0.5\,m^3\,m^{-2}\,h^{-1}$ is suggested if the nutrients be intended as parameters that should be controlled by HRF.

(6) HRF showed an adequate capacity to retain nitrogen, phosphorous, and COD during the filtration runs, which can be considered as an alternative for aerated lagoons tertiary treatment.

(7) Applying the other kinds of media with higher specific surface may improve the removal efficiency of phosphorous from the aerated lagoon effluent. Also, using aeration-assisted roughing filter systems may enhance the elimination of nitrogen because the oxidation of ammonia can be occurred.

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