J. Saf. Environ. Health Res. 1(1): 1–5, Autumn 2016
DOI: 10.22053/jsehr.2016.33380

ORIGINAL RESEARCH PAPER

Nutrient Elimination from Effluent of Municipal Wastewater Treatment Plant Applying Horizontal Roughing Filter

Mohammad Khazaei[1], Nader Yousefi[2], Amir Hossein Mahvi[2,3,4*], Amin Bagheri[5], Kamal Ghadiri[6]

[1]Research Center for Environmental Pollutant, Qom University of Medical Sciences, Qom, Iran.
[2]School of Public Health, Tehran University of Medical Sciences, Tehran, Iran.
[3]National Institute of Health Research, Tehran University of Medical Sciences, Tehran, Iran.
[4]Center for Solid Waste Research, Institute for Environmental Research, Tehran University of Medical Sciences, Tehran, Iran.
[5]Department of Environmental Health Engineering, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
[6]Shahroud University of Medical Sciences, Shahroud, Iran.

Received 17 October 2016; Revised 7 November 2016; Accepted 1 December 2016; Available online 27 December 2016

ABSTRACT: High levels of turbidity and suspended solids are the major disadvantages of aerated lagoons. Aerated lagoon effluent filtration was investigated by Horizontal Roughing Filter (HRF). Removal efficiencies were determined by examining total phosphorus (TP) and total Kjeldahl Nitrogen (TKN) from HRF influent and effluent, simultaneously. HRF pilot system located on effluent pump station of Qom wastewater treatment plant and was put into operation at the filtration rate of 1 m^3/m^2.h. The main objective was to evaluate the performance of horizontal roughing filter for nutrient removal from aerated lagoon effluent. The filter was fed with continuously aerated lagoon effluent during a 62 days filtration run period. TKN and TP removal efficiencies were 46.6% and 53.8%, respectively. The average inlet and outlet TKN during filtration were 14.49 ±1.63 and 7.73 ±2.84 mg NH_3/L, respectively. Moreover, TP was measured 5.7 ±0.83 and 2.63 ±0.63 mg P/L for filter inlet and outlet, respectively. It was shown that horizontal roughing filter has a significant effect on total Kjeldahl nitrogen ($p<0.001$) and total phosphorus removal ($p<0.005$).

KEYWORDS: *Total Kjeldahl Nitrogen, Total Phosphorous, Horizontal Roughing Filter, Aerated Lagoon*

Introduction

Aerated lagoons are not as effective as facultative ponds in removing ammonia nitrogen or phosphorus unless designed for nitrification. Diurnal changes in pH and alkalinity that affect removal rates for ammonia nitrogen and phosphorus in facultative ponds do not occur in aerated lagoons [1]. In addition, lagoon treatment systems are not very efficient in producing effluents with low suspended solids concentrations [2].

Over several decades, much research was conducted on the removal of algae and nutrients in the effluent of aerated lagoons [3]. A wide range of processes was investigated to economically further treatment of aerated lagoon effluent [4]. The intermittent sand filter is one of the prevalent processes in aerated lagoon effluent treatment [3]. This kind of filtration technology has some disadvantages such as land requirement, regular maintenance, odor problems, filter media availability, media clogging and sensitivity to cold temperatures [5].

However, there are several available filtration technologies for removal of phosphorus from wastewater effluent along with turbidity and TSS contents. Two–stage filtration is one of them which can reduce effluent phosphorus concentration less than 0.02 mg/L [6].

Roughing filters are long troughs open to the atmosphere with a series of the flow–through compartment containing decreasing sizes of gravel media. The gravel media is often consists of crushed river rocks ranged between 2 and 20 mm average diameter and filtration rate between 0.3 and 1.5 m^3 /h.m^2 [7]. Roughing filters are most frequently used ahead of slow sand filters when the raw water source contains high turbidity or is subjected to frequent runoff events. Its media can cause water to reach laminar flow condition during filtration period. Here, the gravel surface serves as plates in plate settlers. As the water flows through the filter bed, suspended materials deposit on the gravel surfaces. To remove the sludge, gravels should be agitated to lose particles attached them. Thereafter, particles accumulate at the bottom of the filter vessel [8, 9].

Collins reported that biological growth developed on filter media may improve particle removal efficiency in roughing filters due to increased stickiness of filter media [10]. It is reported that TSS removal efficiency of 90% could be attained for concentrations of 50 – 200 mg/L, and 50% to 90% for concentrations 5 – 50 mg/L entering roughing filter [11].

This research examined total Kjeldahl nitrogen and total phosphorus removal by the horizontal–flow roughing filter. A general objective of the study was to evaluate the performance of horizontal roughing filter for aerated lagoon effluent upgrading.

Materials and methods

Horizontal flow roughing filter (HRF)

The design and sizing of the pilot plant (HRF) were guided by Wegelin [7] design criteria based on the preliminary raw water quality data obtained prior to the commencement of the full pilot plant study.

Filtration rate of 1 m/h was chosen. Samples were taken three times a week for a period of 62 days. With the use of Wegelin design guidelines, the following design criteria of HRF

* Corresponding Author Email: *ahmahvi@yahoo.com*
Tel.: +98 2188 954 914; Fax: +98 216 462 267
Note. Discussion period for this manuscript open until January 31, 2017 on JSEHR website at the “Show Article”
http://dx.doi.org/10.22053/jsehr.2016.33380

unit were obtained (Table 1). As shown in Fig. 1, three compartments were used. The filter was divided into three parts: 1) the inlet structure, 2) the outlet structure, and 3) the filter bed.

Table 1. Design criteria of HRF pilot.

Effective Size(d_g)* (mm)	Uniformity Coefficient (U_C)	Compartment Length (m)
4.8	2.5	1.6
5	2.5	1.3
6.8	1.4	0.9

* The effective size of the filter material in each compartment.

The filter was composed of three different beds that each was placed in separate compartment. Perforated walls between compartments made allowance for water horizontal passing through the filter bed. Gravel size was decreased from the beginning to the end of the filter. The first compartment was filled with filter material of effective size 12 – 18 mm, then 8 – 12 mm in the second compartment and 4 – 8 mm in the last compartment.

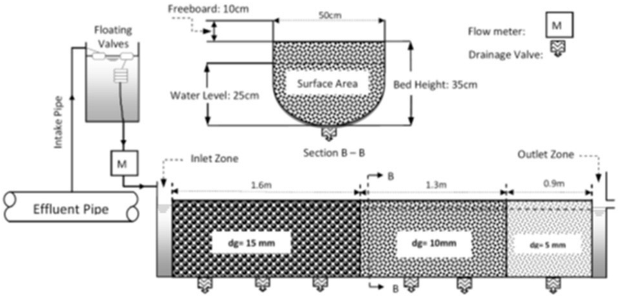

Fig. 1. Schematic layout of the pilot system.

The filter bed was provided with underdrain systems enabling hydraulic sludge extraction (flushing) to be carried out after a certain running period when the resistance in bed was observed to be increasing. This was checked via a raise in the effluent level in the inlet zone.

Aerated lagoon effluent

Qom wastewater treatment plant is based on aerated lagoon system which receives municipal wastewater. Table 2 shows some major constituents of Qom wastewater treatment plant.

Sampling and analytical methods

Samples were taken from the pilot system during 62 days which consisted of 30 sampling dates. During the sampling period, approximately 2 – 4 samples were taken every week. On each sampling date, two grab samples were collected from pilot influent and effluent zone (Fig. 1). The percentage removal of TKN and TP was calculated as the difference between influent and effluent concentrations on the same sampling occasion. On the basis of all removal rates for the entire period, the mean TKN, and TP removal percentages were determined.

Samples were collected from September 13 to November 12, 2011. The experimentation was organized so that both the high flow (wet season) and low flow (dry season) quantities were covered during this period.

Immediately after sampling, samples were taken to be analyzed in the laboratory. The TKN and TP concentrations were analyzed using the methods 4500–N_{org}.B and 4500–P.A, respectively following standard methods [12].

Roughing filter operation

HRF pilot system was installed near the pumping station being fed with effluent discharge pipe. Pumping station of wastewater treatment plant was active 24 hours a day. The pilot system was fed with a small pipe connected to the main discharge pipe of the pumping station. Fig. 1 shows a schematic layout of the pilot system and its relationship with wastewater treatment plant effluent. One filtration rate 1 $m^3/m^2.h$ was tested in this study.

Statistical analysis

Variables were compared with Paired Sample–T test and are presented as means ± standard deviations. All statistical analyses were performed using SPPS version 18.5 (SPSS Inc., Chicago, IL, USA).

Result and discussion

A continuous flow of aerated lagoon effluent was passing from the horizontal–flow roughing filter during 62 days sampling period. Qom wastewater treatment plant No. 1 is based on aerated lagoon system which receives municipal wastewater. Table 2 shows some major constituents of Qom wastewater treatment plant.

Total Kjeldahl Nitrogen

As illustrated in Fig. 2(B), the removal efficiency of total Kjeldahl nitrogen was 15 percent in the 5th sample (10th day of sampling period) and it reached up to 75 percent in the 25th sample (after the 50th day of sampling period). Results from table 3 showed that the average concentration of total Kjeldahl nitrogen (TKN) in HRF inlet zone was 14.49 ±1.63 mg NH_3/L. On the other hand, it was the TKN average concentration of aerated lagoon effluent during HRF run time. In the meantime, the average concentration of TKN in outlet zone of HRF was 7.73 ±2.84 mg NH_3/L. From comparing the means with Pair–T test statistical analysis, it appears that there is a significant difference between inlet and outlet TKN average concentrations ($p<0.001$). TKN removal efficiency by the horizontal roughing filter was 46.6 percent at 1 $m^3/m^2.h$ filtration rate (Table 3).

Table 2. Some major constituents of Qom wastewater treatment plant (Q= 186 ±62 L/s).

Operation parameter	Raw influent (mg/L)	Secondary effluent (mg/L)
BOD_5	200 ±36	70 ±11
COD	375 ±57	142 ±16
TSS	215 ±33	87 ±19

Table 3. Average concentrations of TKN and TP in the horizontal roughing filter influent, effluent, filtration efficiencies, and loading rates.

Location	TKN (mg NH_3-N/L)	TP (mg P/L)
Inlet	14.49 ±1.63	5.7 ±0.83
Outlet	7.73 ±2.84	2.63 ±0.63
Removal Efficiency (%)	46.6	53.8

As recognized from Fig. 2(A), the difference between inlet and outlet concentrations at the beginning of filtration run (first to twentieth day) was 2.7 mg/L but this difference at the end of filtration run (fortieth to sixtieth day) reached 9.66 mg/L.

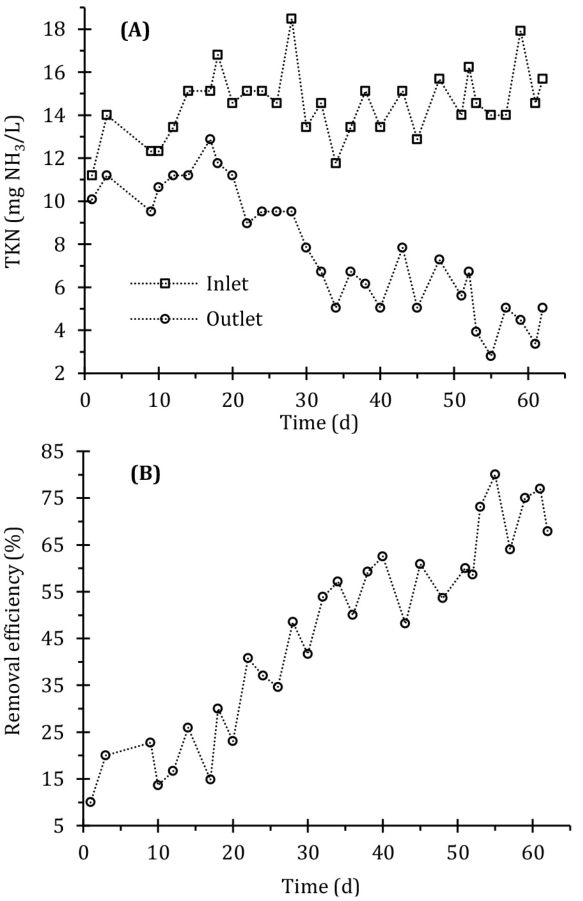

Fig. 2. (A) Total Kjeldahl nitrogen contents of inlet and outlet zones of the horizontal roughing filter. (B) Total Kjeldahl nitrogen removal efficiencies during operating period of the horizontal roughing filter.

Total Kjeldahl nitrogen removal from the horizontal roughing filter (filtration rate 1 $m^3/m^2.h$) was 46.6 percent.

During sampling, the removal efficiency of total Kjeldahl nitrogen was 15 percent at the outset and reached 75 percent in the end. It showed a 60% efficiency increase during the 40–day filter operation. Clogging and head loss increase was not noticeable during operation period (62 days); therefore, it was not necessary to interrupt filtration because of gravel bed cleaning (hydraulic washing).

The average TKN concentration in the pilot effluent was 7.73 mg NH_3/L which is under accepted range of EPA federal standard for secondary effluent (10 mg NH_3/L). This level is out of EPA federal standard for reuse (4 mg/L as NH_3) and aquifer discharge with secondary effluent (1.3 mg/L as NH_3) [13]. Meanwhile, pilot effluent TKN concentration met European Community (EC) standard for municipal effluent (15 mg/L as NH_3) [14].

TKN concentration of secondary effluent of municipal wastewater ranges from 20 up to 40 mg NH_3/L [15–17]. Rich et al. measured similar effluent concentration in the final cell of dual power multi–cellular (DPMC) aerated lagoon with total Kjeldahl nitrogen of 35 mg NH_3/L [18].

Idelovich carried out the long–term performance of soil aquifer treatment (SAT) for effluent reuse and measured of 57 percent total nitrogen (TN) removal. Sampling took over 20 years, total nitrogen concentration before SAT ranged from 5 to 30 mg/L and concentration after SAT was 5 to 10 mg/L. Authors concluded that nitrogen was efficiently removed by a combination of ammonia adsorption and biological nitrification–denitrification. There are several similarities between the horizontal roughing filter and filtration through the upper soil layer of SAT such as horizontal flow, gravel size, lack of backwash, aeration, algal growth, and chemical added mechanisms [19].

Sedlak proposed TKN concentration of 8 mg/L as NH_3 for secondary municipal treated effluent [15]. Stoddard et al. have reported amounts of TKN concentration during various municipal wastewater treatment processes. Based on these findings, TKN concentration of secondary effluent is 19.4 mg/L and is reduced to 5.9 mg/L after tertiary treatment [17].

Gersberg et al. conducted a research about nitrogen removal in the artificial wetland. Their results revealed that in non–vegetated and non–carbon (methanol) addition phase, nitrogen removal was 25 percent. When methanol is added to supplement the carbon supply and bacterial denitrification is stimulated, removal efficiency is extremely high (95 percent removal of total nitrogen) [20].

Because of several similarities, HRF efficacy during nitrogen removal could be compared with free surface wetlands which serve as lagoon effluent treatment (horizontal flow, gravel size, loading rates, construction material and operational aspects). TKN removal efficiency of 37.3 percent was gained by lagoon effluent treatment [21]. Similar studies with a horizontal subsurface wetland on dairy parlor wastewater showed 48.5 percent TKN removal [22].

However, HRF bed surface is not cultivated by appropriate plants, such as horizontal subsurface wetlands, but its TKN removal efficiency is equal to wetland systems. This proportional suitable removal efficiency may be due to low filtration rate (1 $m^3/m^2.h$) and specific bed compartments configuration (decreasing gravel size from HRF inlet zone to its outlet).

Total Phosphorous

The average inlet concentration of total phosphorus was 5.70 ±0.83 mg P/L. At the same time, the average outlet concentration of TP during the run time was 2.63 ±0.63 mg/L (Table 3). The difference between average inlet and outlet concentrations of samples taken from the first 20 days of the sampling period (consisting 9 samples) was 2.16 mg P/L. The average difference between inlet and outlet concentrations at the end of filtration period including 12 samples (the last 20 days of the pilot run time) was 3.78 mg P/L (Fig. 3(A)).

From the comparison of means with Pair–T test statistical analysis, it appears that there is a significant difference between inlet and outlet TP average concentrations ($p<0.001$). Total phosphorus removal efficiency by the horizontal roughing filter was 53 percent at 1 $m^3/m^2.h$ filtration rate (Table 3).

As revealed from Fig. 3(B), the removal efficiency of total phosphorus was 45 percent in the 9th sample (20th day of sampling period) and reached more than 75 percent in the 24th sample (after the 5th day of sampling period).

It was observed that influent concentration of total phosphorus (TP) ranged from 4.73 to 7.53 mg P/L, whereas the effluent concentration of TP did not proceed from 3.93 mg/L during filtration period (Fig. 3(A)).

Environmental protection organization of Iran set a maximum level of phosphorus for discharge in surface waters and absorption wells as 6 mg P/L [23]. As noted above, the average concentration of total phosphorus during the study run–time was 2.63 ±0.63 mg P/L, although the phosphorus concentration of aerated lagoon effluent (5.7 ±0.83 mg P/L) is also under the standard level (Table 3).

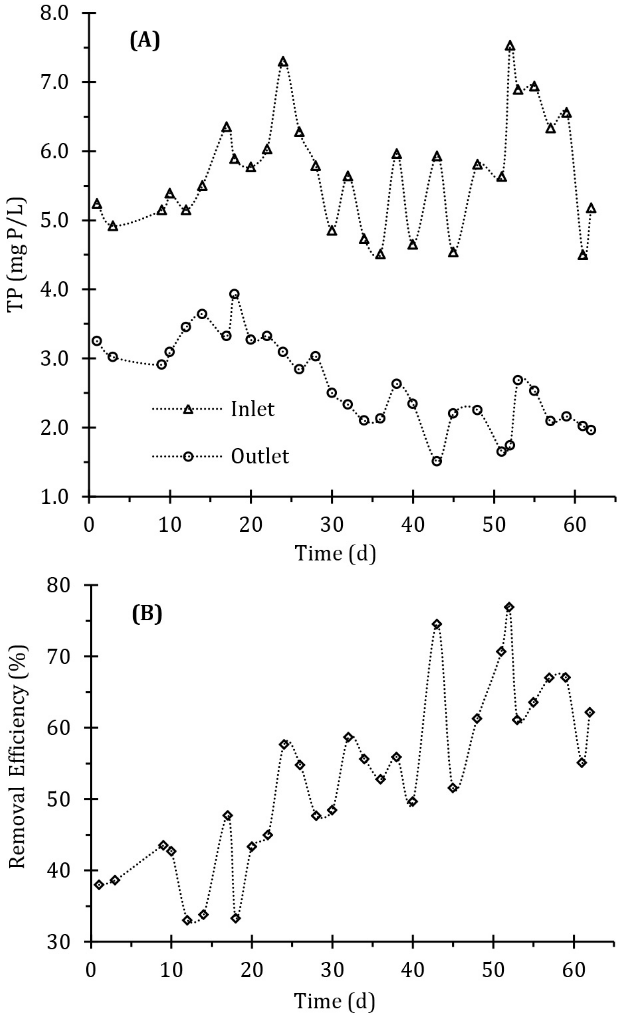

Fig. 3. (A) Total phosphorus contents of inlet and outlet zones of horizontal roughing filter. (B) Total phosphorus removal efficiencies during operating period of horizontal roughing filter.

Average TP concentration in the pilot effluent was 3.1 mg/L as PO_4 which was out of accepted range of EPA federal standard for secondary effluent (1.3 mg/L as PO_4). Average TP concentration in the pilot effluent was also out of EPA federal standard for reuse (1.3 mg/L as PO_4) and aquifer discharge with secondary effluent (0.02 mg/L as PO_4) (13). It should be mentioned that pilot effluent TP concentration was unaccepted regarding European Community (EC) standard for municipal effluent (2 mg/L as PO_4) [14].

Total phosphorus effluent concentration from dual power multi–cellular (DPMC) aerated lagoon (such as Qom wastewater treatment plant) was reported 1.2 mg/L by Rott et al. (1996). Also, Rott et al. determined TP concentration of intermittent sand filter (ISF) operated after DMPC aerated lagoon as 0.8 mg/L which means a 33 percent removal efficiency of ISF [24].

Intermittent sand filters (ISF) are well–known systems for aerated lagoon effluent treatment (polishing) and their design parameters have been determined from the 1980s [16, 25] but roughing filter design parameters are prepared for surface water resources pretreatment [7].

In surface water treatment facilities in which HRF was operated as pretreatment system prior to slow sand filter (SSF), phosphorus removal was reported to be 18.7 percent [26]. Other types of filters such as light weight aggregated – calcium (LWA–Ca) filters are used for phosphorus removal from raw water. The LWA–Ca filter media sizes of 2 – 4 mm are similar to HRF media (4.8 mm; that is the media size of the third compartment which consists of fine gravels). The LWA–Ca filter could remove 27 percent of phosphorus (inlet concentration: 0.5 mg/L) when the hydraulic rate was 7 $m^3/m^2.h$ [27].

Removal of phosphorus by biological roughing filter fed with primary settling tank effluent was reported as 25.7% without chemical pretreatment [28].

Janssen et al. (2010) reported 70% phosphorus removal by the horizontal sand filter in municipal effluent reuse system [29]. Noticeable phosphorus removal obtained by Janssen et al. (2010) may be due to the effect of grain size and filter depth which were 1 mm and 7.5 m, respectively. Therefore, it is acceptable that HRF with 3.8–meter bed length and gravel size ranging from 6.8 to 4.8 mm (table 1) has phosphorus removal efficiency close to 47 percent (Table 3).

Conclusions

- Although wastewater treatment plant effluent (filter effluent) characteristics such as TKN and TP were changed daily, the HRF effluent quality was observed almost consistent during the study period.
- The HRF effluent characteristics (TKN and TP) slightly reduction through filtration run was not related to influent concentrations and may be described by biofilm proliferation of gravel beds.
- Although HRF retention time is 3.8 hours (based on filtration rate of 1 $m^3/m^2.h$ and total bed length of 3.8 m), both TKN and TP removal efficiencies are noticeable (more than 46 percent).
- TKN and TP removal efficiencies may be attributed to the incorporation of bed multilayer and decreasing gravel size from inlet to the outlet zone (Fig. 1).
- Because of HRF design parameters based on surface water pretreatment, it seems indispensable that new design parameters be determined if HRF is to serve as tertiary treatment unit of aerated lagoon effluent.

Acknowledgments

We would like to thank water and wastewater organization of Qom province (ABFA–Qom). This work was supported by the Qom University of medical sciences (MUQ).

References

[1] EPA, Wastewater technology fact sheet: aerated, partial mix lagoons, in, Environmental Protection Agency, United States, 2002.
[2] R. Crites, G. Technobanoglous, Small and Decentralized Wastewater Management Systems, McGraw–Hill, New York, 1998.
[3] M. Khazaei, S. Nasseri, M.R. Ganjali, M. Khoobi, R. Nabizadeh, A.H. Mahvi, S. Nazmara, E. Gholibegloo, Response surface modeling of lead (II) removal by graphene oxide–Fe_3O_4 nanocomposite using central composite design, Journal of Environmental Health Science and Engineering, 14 (2016) 1.
[4] L.G. Rich, Aerated lagoon technology, Clemson University, United States, 2003.
[5] J. Ebeling, S. Tsukuda, J. Hankins, C. Solomon, Performance evaluation of a recirculating sand filter and peat filter in West Virginia, Small Flows Quarterly, 4 (2003) 27–29.
[6] E. Metcalf., Wastewater Engineering: Treatment and Rse, McGraw–Hill, New York, 2003.
[7] M. Wegelin, Surface water treatment by roughing filters: a design, construction and operation manual, SANDEC, 1996.

[8] J. Crittenden, M.W. Harza, Water Treatment: Principles and Design, John Wiley & Sons, New York, 2005.
[9] S. Rooklidge, L. Ketchum, Calcite–amended horizontal roughing filtration for clay turbidity removal, Aqua, 51 (2002) 333–342.
[10] M. Collins, J. Cole, C. Westersund, D. Paris, Assessing roughing filtration design variables, Water Supply, 12 (1994).
[11] M. Wegelin, M. Boller, R. Schertenleib, Particle removal by horizontal–flow roughing filtration, J. Water SRT– Aqua, 36 (1987).
[12] A. APHA, WEF, Standard Methods for the Examination of Water and Wastewater, in, American Public Health Association, American Water Works Association, and Water Environment Federation, United States, 2005.
[13] D. Smith, R. Otis, M. Flint, Florida passive nitrogen removal study (Final report), in, Florida Department of Health, Tallahassee, Florida, United States, 2008.
[14] O.A.-R. Sanusi, Nitrogen reduction in Luleå kommun wastewater effluent, in, Lulea University of Technology, Sweden, 2007, pp. 57.
[15] R.I. Sedlak, Phosphorus and Nitrogen Removal from Municipal Wastewater: Principles and Practice, CRC Press, 1991.
[16] L. Rich, High Performance Aerated Lagoon Systems, Clemson Univ., SC United States, (1999).
[17] A. Stoddard, J.B. Harcum, J.T. Simpson, J.R. Pagenkopf, R.K. Bastian, Municipal Wastewater Treatment: Evaluating Improvements in National Water Quality, Wiley. com, 2003.
[18] L. Rich, Mathematical model for dual–power level, multicellular (DPMC) aerated lagoon systems, Developments in environmental modelling, 7 (1985) 147–168.
[19] E. Idelovitch, N. Icekson–Tal, O. Avraham, M. Michail, The long–term performance of Soil Aquifer Treatment (SAT) for effluent reuse, Water Supply, 3 (2003) 239–246.
[20] R. Gersberg, B. Elkins, C. Goldman, Nitrogen removal in artificial wetlands, Water Research, 17 (1983) 1009–1014.
[21] K. Cameron, C. Madramootoo, A. Crolla, C. Kinsley, Pollutant removal from municipal sewage lagoon effluents with a free–surface wetland, Water Research, 37 (2003) 2803–2812.
[22] P. Mantovi, M. Marmiroli, E. Maestri, S. Tagliavini, S. Piccinini, N. Marmiroli, Application of a horizontal subsurface flow constructed wetland on treatment of dairy parlor wastewater, Bioresource Technology, 88 (2003) 85–94.
[23] A. Mesdaghinia, D. Rabbani, S. Nasseri, F. Vaezi, Effect of coagulants on electrochemical process for phosphorus removal from activated sludge effluent, Iran J Public Health, 32 (2003) 45–51.
[24] G.G. Rott, Alternative to $CBOD_5$–based load allocation studies on low–dilution–ratio streams, Journal of Environmental Engineering, 122 (1996) 669–671.
[25] E.J. Middlebrooks, J. Reynolds, J. Montgomery, C. Middlebrooks, R. Schneiter, Design Manual: Municipal Wastewater Stabilization Ponds, in, Environmental Protection Agency, Cincinnati, OH (USA). Center for Environmental Research Information, 1983.
[26] G.E. El–Taweel, G.H. Ali, Evaluation of roughing and slow sand filters for water treatment, Water, air, and soil pollution, 120 (2000) 21–28.
[27] L. Pesonen, A. Pasila, F. Teye, Filter material prepared by grinding, comprising Calcium Hydroxide, in, WO Patent 2,006,134,215, 2006.
[28] H.N. Wiechers, A.S. Louw, N.C. Thirion, K.E. Brodisch, Upgrading of biological filter sewage purification processes for phosphate and nitrogen removal, Water S. A., 10 (1984) 205–210.
[29] A. Janssen, J. van Agtmaal, W.v. den Broek, A. Geilvoet, H. Menkveld, J.–C. Schrotter, J.v. der Graaf, Prefiltration of wastewater effluent: Effects on foulants and performance during dead end ultrafiltration, Desalination, 250 (2010) 855–860.

AUTHOR(S) BIOSKETCHES

Khazaei, M., Ph.D., Assistant Professor, Faculty of Health, Department of Environmental Health Engineering, Qom University of Medical Sciences, Qom, Iran. Email: *khazaei@muq.ac.ir*

Yousefi, N., Ph.D., Assistant Professor, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran. Email: *yousefinader@gmail.com*

Mahvi, A.H., Ph.D., Assistant Professor, Faculty of Health, Department of Environmental Health Engineering, Tehran University of Medical Sciences, Tehran, Iran. Email: *ahmahvi@yahoo.com*

Bagheri, A., Ph.D., Assistant Professor, Department of Environmental Health Engineering, Shahid Beheshti University of Medical Sciences, Tehran, Iran. Email: *bagheri.sbmu@gmail.com*

Ghadiri, K., Ph.D., Assistant Professor, Shahroud University of Medical Sciences, Shahroud, Iran. Email: *kamalgh2005@gmail.com*

COPYRIGHTS

HOW TO CITE THIS ARTICLE

M. Khazaei, N. Yousefi, A.H. Mahvi, A. Bagheri, K. Ghadiri, Nutrient Elimination from Effluent of Municipal Wastewater Treatment Plant Applying Horizontal Roughing Filter, Journal of Safety, Environment, and Health Research, (2016) 1–5.

DOI: 10.22053/jsehr.2016.33380

URL: http://jsehr.net/article_33380.html