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The Effect of HLRs on Nitrogen Removal by Using a Pilot-scale Aerated Steel Slag System

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Abstract. Discharge from domestic wastewater treatment plant amongst the main sources of nitrogen pollution in the environment. However, to remove nitrogen conventionally in domestic wastewater require high cost and complex chemical treatment method. Vertical flow aerated rock filter emerged as one of attractive alternative wastewater treatment method due to simplicity and compactness of the system. However, the application is yet to be developed in warm climate countries in particular Malaysia. Therefore, this study was conducted to investigate the effect of hydraulic loading rate (HLR) to the performance of a pilot-scale Vertical Flow Aerated Rock Filter (VFARF) in removing nitrogen from domestic wastewater using pilot-scale VFARF systems with steel slag as the filter media. Furthermore, this study has been designed to focus on the effects of two HLRs; 2.72 and 1.04 m^3/m^3.day. Influent and effluent of the filter systems were monitored biweekly basis for 11 weeks and analyzed for selected parameters. Results from this study shows that the VFARF with HLR 1.04 m^3/m^3.day has performed better in terms of removal ammonium-nitrogen and TKN as the system able to remove 90.4 ± 6.9%, 86.2 ± 10.7%, whilst the VFARF with 2.72 m^3/m^3.day remove 87.4 ± 9.9%, 80 ± 11.7%, respectively. From the observation, it can be concluded that nitrogen removal does affect by HLR as the removal in lower HLR system was higher due to high DO level in the VFARF system with 1.04 m^3/m^3.day which range from 4.5 to 5.1 mg/L whilst the DO level was slightly lower in the VFARF system with 2.72 m^3/m^3.day in the range of 3.7 to 4.5 mg/L.

1 Introduction

Rock filter system has been widely used for more than 30 years ago in the United States to remove algal solids and associated BOD in effluents mainly from primary maturation ponds [1]. Conventionally, a rock filter is designed to remove algae suspended solids in pond effluent. The pond effluent undergoing further polishing treatment within the rock filter system is allowed to travel either horizontally or vertically through a submerged porous rock media bed. Whilst the liquid flows through the void spaces, the algae get

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trapped on the rock media surfaces. The use of rock filters for algae removal has been studied extensively at Eudora, Kansas; California, Missouri; and Veneta, Oregon [2]. Filtration is one of the method for the treatment of water and it is one of the oldest, simplest and widely used methods. It is the process of removing suspended solids from raw water by passing the water through a permeable fabric or porous bed materials. For large quantity of water, sand is generally used as the filter medium because it is cheaper and effective. Simplicity of filtration makes the process attractive for use in small communities and developing nations. Mara [3] also highlighted that the aerated rock filter system is an ideal treatment train for secondary treatment, because of their land area savings and potentially replacing the requirement for maturation ponds.

Rock filters has been used to treat effluents from domestic Wastewater Treatment Plant. From the previous study conducted by Hamdan (2010), an aerated system was introduced in rock filter system to remove ammonia nitrogen and phosphorus. Aeration also improve BOD and TSS removals. While, unaerated system primarily for algal suspended solids and organic matter removal, BOD [4]. Most rock filter operating systems were designed for horizontal flow with the rock bed placed at or near the effluent end of the final cell in the lagoon system. In general, vertical flow systems, such as ones located in Veneta, Oregon and West Monroe, Louisiana, perform better than horizontal flow systems.

Furthermore, previous study conducted by Hamdan [5], indicated that the filter using vertical flow aerated rock filter (VFARF) facilitate nitrogen removal better than the horizontal flow aerated rock filter (HFARF). The systems are also moderately inexpensive, have low energy requirements and do not require highly skilled personnel [6]. However, the VFARF system design is needed to be developed under warm climate as has been ssuggested in Hamdan and Mara [7]. Therefore, this study was conducted by using the VFARF system with low cost media which is steel slag. The purpose of this investigation was to evaluate the effect of different HLRs on ammonia nitrogen removal from domestic wastewater under Malaysian condition.

2 Materials and methods

2.1 Pilot-scale unit

Two identical vertical-flow aerated RF (VFARF) systems with 2.0 m height x 0.3 m diameter have been developed at the experimental station were operated in parallel at our experimental station at Wastewater Treatment Plant, Batu Pahat, Johor, Malaysia (1050’37.05”N, 102056’49.43”E). The WWTP comprises domestic wastewater from residential area consists of 15800 of population equivalent (P.E) about 90% and the rest 10% is from industrial wastewater. Wastewater after pre-treatment was pumped into primary sedimentation tank and then pumped into two parallel VFARF base using 15mm reinforced plastic pipework connected to a polyvinyl chloride (PVC) inlet strainer using peristaltic pumps with W77200-62 pump heads (Cole-Parmer Masterflex L/S Model 7524-40, USA). The Cole Parmer air flow meters were installed at the air inlet of the VFARFs and aerated using JUN Air Compressor (OF302-25B, Denmark). The pilot-scale VFARF systems have been operated at 1.04 m3/m3.day and 2.72 m3/m3.day and was maintained at 10 L/min of aeration rate using blast furnace slag media with 10-20 mm grain size.

2.2 Wastewater sampling and analysis

For this study, wastewater influent and effluent samples have been analyzed twice a week for the selected parameters including TKN, AN, DO, and nitrate, for both VFARF systems.

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All the sampling, handling, preservation and laboratory analyses have been conducted according to *Standard Methods for Water and Wastewater Examinations* [8]. Laboratory analysis of collected samples were carried out at Wastewater Engineering Laboratory, Faculty of Civil and Environmental Engineering, UTHM. The VFARF performance have been monitored throughout this study. Final effluent quality of both VFARF systems then compared with Effluent Standard B of Malaysian Environmental Quality (Sewage) Regulations 2009.

3 Results and discussions

3.1 Total kjedhal nitrogen removal

Average concentrations of TKN in the influent was at 37.9 ± 17.4 mg NH_3- N/L. Effluent of the VFARF system average at 7.32 ± 5.1 mg NH3- N/L for 2.72 m^3/m^3.d whilst for HLR 1.04 m^3/m^3.d the average was at 4.9 ± 4.6 NH_3- N/L. TKN was consistently eliminated more efficiently in the VFARF system with HLR 1.04 m^3/m^3.d with highest value of removal efficiency. The average removal efficiencies in the VFARF system with HLR 2.72 m^3/m^3.d was at 80 ± 11.7% whereas their average removal efficiency in the VFARF system with lower HLR which is 1.04 m^3/m^3.d was at 86.2 ± 10.7 during the monitoring period as illustrated in Fig 1 represents these value. TKN concentration in the effluent was mainly in the form of ammonia [12]. As the HLR reduced, the removal efficiency was increased. According to Gerardi [12], the value for TKN is ranged from 8 to 35 mg NH_3- N/L. VFARF with HLR 1.04 and 2.72 m^3/m^3.d is within the limit. TKN removal were found to be relatively high after the wastewater was further treated in both VFARF filters. Results from this study shows that the VFARF with HLR 1.04 m^3/m^3.d has performed better in terms of removal TKN. However, both effluent systems however do not exhibit a significant different in terms of removal efficiencies. TKN removal were found to be relatively high after the wastewater was further treated in both filter.

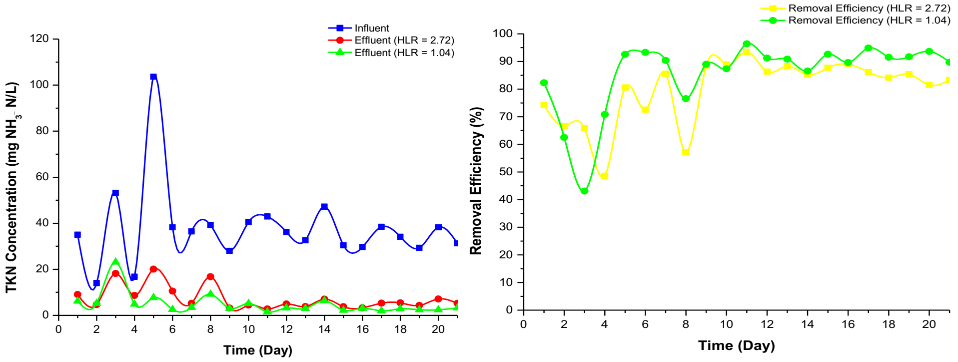

Fig. 1. The VFARF Influent and Effluent TKN Concentration and Their Removal Efficiency.

3.2 Ammonium nitrogen removal

Influent concentrations of AN entering the VFARF systems range from 4.90 to 33.41 mg NH_4- N/L. with an average of 25.3 ± 7.8 mg NH_4- N/L. Average effluent concentration of ammonium nitrogen (AN) for HLR 2.72 m3/m3. d was at 2.8 ± 1.5 mg NH4- N/L during

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this monitoring period whilst for HLR 1.04 m3/m3. d the average was at 2.2 ± 1.4 mg NH4- N/L, respectively (see Fig 2).

The concentration of ammonia nitrogen in the influent is higher than effluents in both VFARF systems. Ammonia nitrogen is mainly removed through nitrification process. The presence of ammonia nitrogen is due to incomplete nitrification process in the filter system. Nitrified wastewater is then can be further reduced in denitrification zone which is required anoxic condition. The highest removal efficiency is 97.69% over all sampling periods. Hence, the average removal efficiency was at 87.8 ± 9.9% for VFARF filter with HLR 2.72 m3/m3. d and 90.4 ± 6.9% for the lower HLR which is 1.04 m3/m3. d. The average removal efficiency performed slightly better in VFARF with lower HLR (1.04 m^3/m^3.d). This was attributable to the higher dissolved oxygen content, and a better nitrification rate [14]. Through the VFARF systems, ammonia nitrogen can be removed efficiently from domestic wastewater. In addition, VFARF system is more appropriate due to their ability in removing ammonia nitrogen.The low content of ammonia nitrogen shows the complete nitrification process. Effluents of ammonia nitrogen from both VFARF systems is complying with the effluent permissible limit for 'Standard B' from Environmental Quality (Sewage) Regulations 2009 (PU (A) 432) which is 20 mg/L. The value of ammonia nitrogen must follow standard prior discharge to river because higher ammonia nitrogen discharge to river will affect the aquatic life. As a conclusion, the VFARF system with HLR of 1.04 m^3/m^3.d eliminated AN more successfully than the VFARF system with HLR of 2.72 m^3/m^3.d as their capabilities in removing AN were consistently higher than the VFARF system with 2.72 m^3/m^3.d.

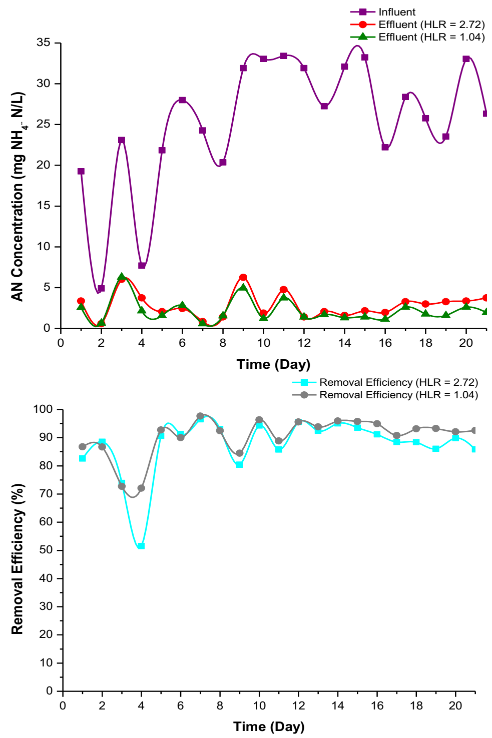

Fig. 2. The VFARF Influent and Effluent AN Concentration and Their Removal Efficiency

Furthermore, high concentration of nitrate-N in the VFARF effluent shows that nitrification process is taking place as AN has been converted to nitrate. An average concentrations of nitrate-N in the VFARF system effluent was 30.6 ± 14.5 mg NO_3-N/L and 33.0± 16.4 mg

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NO3-N/L for HLR 2.72 m^3/m^3.d and 1.04 m^3/m^3.d, respectively as shown in Fig 3. From this observation, conversion of nitrate-N was slightly higher in the VFARF with 1.04 m^3/m^3.d HLR compared to the VFARF with 2.72 m^3/m^3.d HLR. This condition shows that nitrification rate was slightly higher in the system with higher nirate-N concentration in final effluent. Therefore, this observation then supported by nitrification rate data that was relatively higher in the VFARF system with HLR 1.04 m^3/m^3.d compared to VFARF system with HLR 2.72 m^3/m^3.d as illustrated in Fig. 4. Their average nitrification efficiency in the filter with HLR 2.72 m^3/m^3.d was at 80 ± 11.7% whereas their average nitrification efficiency in the filter with HLR 1.04 m^3/m^3.d was at 86.2 ± 10.7%. The rate of nitrification was found to be higher in filter with HLR 1.04 m^3/m^3.d. According to the previous study, the system achieved good nitrification and carbonaceous oxidation rate in treating domestic-strength synthetic wastewater by using vertically moving biofilm systems.

In addition, nitrification rate is also affected by dissolved oxygen (DO) level. It shows that the DO rate of the influent is more than 0.2 mg/1. The rate of the influent is between 0.5 to 2.5 mg/L. At lower DO than 1 mg/L, nitrification slows down in general. DO was found to be higher in the effluent of VFARF with 1.04 m^3/m^3.d whilst the lower DO was determined in the effluent of VFARF with 2.72 m^3/m^3.d. Average DO in effluent with 2.72 m^3/m^3.d and 1.04 m^3/m^3.d was at 4.1 ± 0.4 mg/L and 4.8 ± 0.3 mg/L, respectively. According to Gerardi [12], the nitrification rate was observed to improve at DO concentrations >3 mg/L. When DO drops to below 2 mg/L for an extended period, nitrification would be inhibited. The rates of nitrification are higher when the DO levels in the system are higher. According to the increasing level of DO in the systems, the VFARF pilot-scale system provides more favourable conditions for nitrification to occur as well as further removal of biodegradable organic matters. Hence, the VFARF pilot-scale is appropriate system to enhance the nitrogen removal mainly through nitrification process. As the organic matter in the VFARF influent were sufficiently lowered, the conditions will then allow nitrification to occur. In this environment, the growth of nitrifying bacteria becomes optimal as the nitrifying bacteria use DO and inorganic carbon to convert ammonia to nitrite and nitrate. The consumption of the DO is needed to oxidize ammonia to nitrite and later to nitrate. From this study, it was found that the DO level of the VFARF system with HLR 1.04 m^3/m^3.d. was significantly higher than VFARF system with HLR 2.72 m^3/m^3.d. Concentration of DO has a significant effect on the rates of nitrifier growth and nitrification in biological waste treatment systems [13].

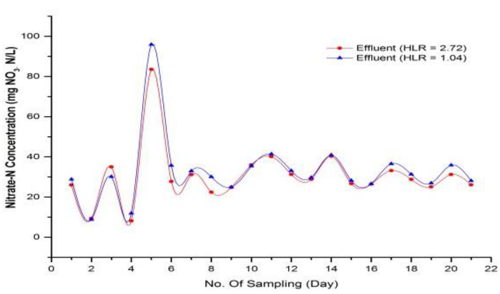

Fig. 3. The VFARF effluents Nitrate-N concentrations

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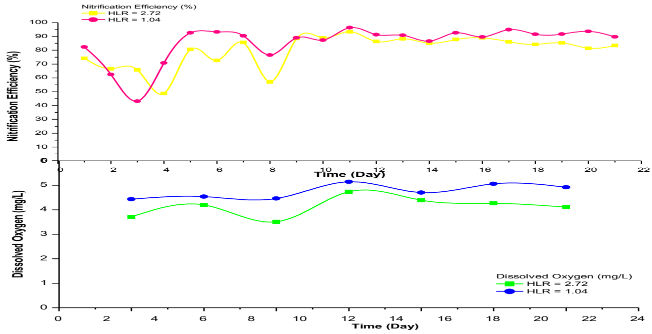

Fig. 4. Nitrification Rate of the VFARF and Their DO profile

4 Conclusion

The filter systems with HLR 1.04 m^3/m^3.d achieved a higher AN and TKN removal efficiency than filter with HLR 2.72 m^3/m^3.d. Nitrogen removal does affect by HLR as the removal in lower HLR system was higher due to high DO level in the VFARF system with 1.04 m^3/m^3.d which range from 4.5 to 5.1 mg/L whilst the DO level was slightly lower in the VFARF system with 2.72 m^3/m^3.d. in the range of 3.7 to 4.5 mg/L. It indicates that, the objective of this study is achieved. Furthermore, both effluents quality of the steel slag filter complies with Malaysian effluent discharge of standard B Environmental Quality (Sewage) Regulations 2009 (PU(A) 432). The application can be developed in warm climate countries in particular Malaysia.

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