Journal of Applied Sciences

ISSN 1812-5654

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 10 (19): 2283-2289, 2010
ISSN 1812-5654

Simplified Integrated Design for Fixed Film Biological Nutrient Removal

[1]Bruce W. Berdanier, [2]Anf H. Ziadat and [3]Anwar Jiries
[1]Department of Civil and Environmental Engineering, South Dakota State, University,
118 Crothers Engineering Hall, Brookings, South Dakota 57007, USA
[2]Department of Civil Engineering, Abu Dhabi Men's College, Higher Colleges of Technology,
P.O. Box 25035, Abu Dhabi, United Arab Emirates
[3]College of Science, Mutah University, P.O. Box 2, Al-Karak-61710, Jordan

Abstract: This objective of this research was to evaluate the efficiency of a developed laboratory scale reactor system that models the treatment of septic tank effluent in a simplified fixed film of carbonaceous biochemical oxygen demand removal along with treatment for biological nutrient removal (CBOD/BNR) in wastewater. The laboratory scale reactor treatment built system operated as an integrated model with the collection system beginning at the source of the wastewater. Using a single stage trickling filter following the septic tank, the laboratory scale reactor system achieved 81% chemical oxygen demand removal, 36% NH_3-N removal and 56% phosphorus removal. The total phosphorus removal averaged 50% during steady state operation of phase one. On the other hand, the two stage filter system achieved 90%, chemical oxygen demand removal and as high as 90% ammonia removal and phosphorus removal of approximately 50%. These results indicate that, chemical oxygen demand, NH_3-N and phosphorus removals can be significantly improved by additional single stage trickling filter system after septic tank treatment. The filter was proven to produce minimum sludge value after seven months of operation. The components of this system are simple and cost effective to build and operate.

Key words: Wastewater, trickling filters, Anaerobic reactor, nitrification, phosphorus

INTRODUCTION

Small communities need simplified wastewater treatment systems. There is a need to consistently accomplish high levels of Carbonaceous Biochemical Oxygen Demand (CBOD) removal and to add treatment for Biological Nutrient Removal (BNR) as the technical need for simplified wastewater treatment, small communities are generally located in more rural areas and may therefore be located on stream reaches with a higher degree of water quality. Trickling filter technology is generally far easier to operate than activated sludge processes and may actually require less space than suspended growth systems when BNR must be achieved. This technology has been very successful in small communities for carbonaceous BOD removal and for nitrification. Such systems would be useful in rural areas of the United States and developing countries such as the country of Jordan (Crites and Tchabanoglous, 1998).

Approximately half of Jordanian households are located in relatively remote rural areas. Wastewater disposal in these areas is accomplished in cesspools or septic tank systems. The country of Jordan has yet to develop awareness in the availability of appropriate techniques and designs for utilizing small-decentralized treatment systems to address wastewater in these rural areas. By 1993, Jordan was reusing approximately 50 million m^3 $year^{-1}$ of treated wastewater almost exclusively for irrigation (FAO, 1999). In the Amman area, the treated wastewater is returned to Seil Zarqa (now an engineering wastewater and runoff conveyance), which flows to the Zarqa River and the King Talal Dam impoundment where it is mixed with surface water runoff and utilized in a pressurized irrigation distribution system in the Jordan Valley (Boom *et al*., 2008). As the reused wastewater is the key component in Jordan's water strategy for irrigation, small-decentralized wastewater treatment systems could be a valuable asset in localized rural areas to produce safe irrigation waters.

Biological Nutrient Removal (BNR) processes have been defined and investigated as a combination of sequential anaerobic, anoxic and aerobic suspended growth systems. The systems have been described in detail by Grady *et al*. (1999). Examination of trickling filter plants for BNR has been limited to upgrading CBOD trickling filter plants with additional suspended growth

Corresponding Author: Dr. Anf H. Ziadat, Abu Dhabi Men's College, Higher Colleges of Technology,
P.O. Box 25035, Abu Dhabi, United Arab Emirates

unit operations (Morgan *et al*., 1999; Cortez *et al*., 2008) evaluating the addition of various types of manufactured media to activated sludge processes (Borregaard, 1997; Lei *et al*., 2009) and utilization of different flow schemes (Johnson *et al*., 1997; Hibiya *et al*., 2003; Ong *et al*., 2003) for removal of nitrogen and phosphorus, as a tertiary treatment scheme. Researchers have investigated the use of Rotating Biological Contactors (RBC) for nitrification and phosphorus removal (Nowak, 2000; Hiras *et al*., 2004; Cortez *et al*., 2008). Nowak also confirmed Nyhuis (1990), finding that if first stage carbon removal is extensive enough, final clarification will not be required as excess sludge production in the nitrification stage will be very low. Investigators have also researched simultaneous nitrification and denitrification in a down flow submerged tower packed with different packing material configurations (Menoud *et al*., 1999; Ong *et al*., 2002). Canziani *et al*. (1999) conducted four years of submerged bio-filter research to try to develop a reliable COD removal and nitrification treatment process without the mandatory requirement for periodic backwashing and reclamation. Galvez *et al*. (2003) maintained final suspended solids concentrations below 35 mg L^{-1} using a down flow submerged aerobic filter followed by an up flow anoxic bio-filter for denitrification with methanol addition. The authors concluded that the final clarifier could have been replaced with a micro strainer or rapid sand filter due to low solids production in the second bio-filter. It is particularly important to have complete hydrolysis of particulate biomass in this treatment process. The success of the simultaneous denitrification process depends on the influent organic matter being soluble to provide a carbon source.

The research project described in this paper investigated a laboratory scale treatment system that would function in an integrated model with the collection system beginning at the source of the wastewater. The components of this system would be simple and cost effective to build and operate. This research and the complete laboratory analysis were conducted at the Environmental Engineering Laboratory of Ohio Northern University, Ohio, USA in 2008.

MATERIALS AND METHODS

Conceptual model: The proposed full-scale system would begin with a STEP/STEG collection system (Crites and Tchabanoglous, 1998; Crites, 2007). The pump or gravity aspect of the system is not critical to the laboratory scale evaluation. Both collection systems can be considered equally for future use as part of the integrated system depending on actual topographic constraints for a given project. The STEP/STEG systems are low cost to install and simple to operate and maintain. They are less susceptible to inflow and infiltration and have lower impact on ground and surface water resources due to less leaking and shallower installation. The systems are less susceptible to sanitary overflows due to their design with check valve protection and the characteristics mentioned above. The reduction in sanitary sewer overflows is also a primary concern of USEPA at the present time (USEPA, 2000).

The septic tank is the first anaerobic zone in the treatment system in the integrated BNR treatment system model proposed. The septic tank also would act as the preliminary physical treatment operation for large particle removal. The removal and/or complete hydrolysis of the particulate matter in the aerobic zone have been identified as necessary for the proper functioning of the BNR system. The sealed collection system could be modeled as an anoxic zone or plug flow reactor for the soluble waste from the septic tank as it is transported to the treatment plant.

Pierce *et al*. (1994), Salvato (1955), Sauer (1977) and Crites and Tchabanoglous (1998) indicated that the concentration of different elements from effluent of septic tanks in residential areas provided less concentration to the majority of elements in comparison to the typical values of concentration obtained from Domestic Wastewater Treatment Plants (DWWTP). Total suspended solids, BOD5 and COD concentrations were by far much less in septic tanks effluents than in DWWTP as shown in a comparison format in Table 1. The preliminary treatment achieved in the STEP/STEG system should provide the impetus for reconsidering higher

Table 1: Comparison of characteristics for typical domestic wastewater and septic tank effluent

Parameters	Typical value for domestic wastewater[1]	Typical value for septic tank effluent[2]	Typical value for septic tank effluent[3]	Typical value for septic tank effluent[4]	Typical value for septic tank effluent[5]	Proposed synthetic waste
	$(\mathrm{mg\ L^{-1}})$					
BOD5	250.0	140	123	150-250	100-140	125
TSS	220.0	101	48	40-140	20-55	50
Phosphorus	8.0	NR	8.7	8.0-12.0	8.0-12.0	8
TKN	40.0	24	NR	50-90	50-90	50
pH	6.8	7.4	NR	NR	NR	7
COD	500.0	280	246	250-500	160-300	250

NR: Not reported. [1]Pierce *et al*. (1994), [2]Salvato (1955), [3]Sauer (1977), [4]Crites and Tchabanoglous (1998) unscreened, [5]Crites and Tchabanoglous (1998) screened

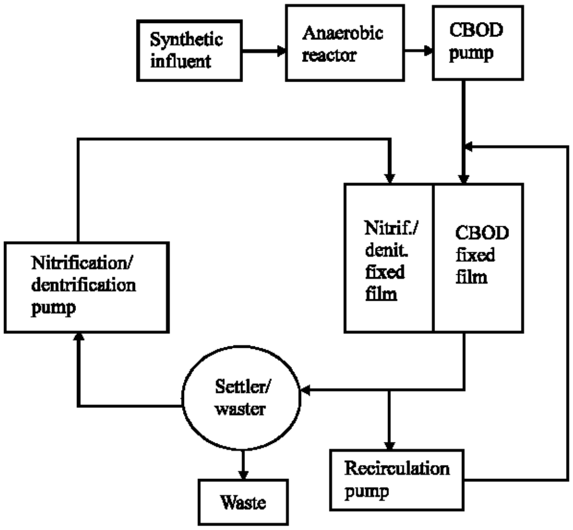

Fig. 1: Schematic of laboratory system

treatment potential from simplified treatment processes such as trickling filters. Additionally, the preliminary treatment operations (screens, comminutors, equalization and grit removal) and the primary treatment operations (primary sedimentation) are not needed at the treatment plant in this proposed design.

Laboratory scale evaluation: The first phase septic tank (anaerobic reactor) consisted of sixty 50 mL gas tight borosilicate glass reactor bottles. Septic tanks were dosed with a synthetic waste on a regular schedule throughout the study period. Additionally, the lead fixed film reactor received an average of 60 mL of septic effluent per day. A conceptual sketch of the laboratory experimental design reactors is shown in Fig. 1.

The septic tank feed stock solution, which was designed to model the dissolved constituents of domestic waste which has been completely hydrolyzed in a septic tank, was mixed as needed and stored in a refrigerator. The mixture was comprised of glucose and glutamic acid dissolved in distilled water to reach BOD_5 of 200-220 mg L^{-1}. Total phosphorus and NH_3-N concentrations was set at 15 and 40 mg L^{-1} respectively. The pH was buffered to 7.0-7.5 and the final mixture had 0 mg L^{-1} Total Suspended Solids (TSS).

A gas tight micro-syringe was used to withdraw the effluent from each septic tank and also to sample the septic tanks for chemical analysis. The effluent from the septic chambers was withdrawn with minimum disturbance to the sludge layer to minimize particulate matter in the influent to the fixed film reactor. The septic tanks and trickling filter(s) were maintained and operated inside a controlled fume hood. The temperature was maintained between 23.2 and 24.4°C during Phase I and Phase II of the investigation. The trickling filter media was cylindrical in shape (2 cm in diameter and 1.5 cm in height).

The septic tanks were initially seeded with 20 mL each of raw primary sludge from the Village of Ada, Ohio Wastewater Treatment Plant (WWTP). The first phase septic tanks were fed on a regular basis without analysis until the sludge began to settle and created a clear supernatant space at the top of the septic tank reactor bottle. The dosing of the Phase 1 trickling filter with the septic tank effluent using a gas tight micro-syringe aerated the wastewater as it was applied to the filter. Aeration at this point in the process is intended to hydrolyze particulate matter and to provide sufficient DO for CBOD removal in the first stage of the fixed film reactor.

RESULTS AND DISCUSSION

During the first phase (Phase I) operation, the COD removal was fairly consistent approaching 81% as a maximum. The final COD concentration leveled off at approximately 200 mg L^{-1}. The influent COD concentration derived from the septic tanks was over 1600 mg L^{-1} initially, with gradual reduction and finally reached 1000 mg L^{-1} by the end of phase one operation. Under the steady state conditions in phase one, ammonia and phosphorus removal averaged 40 and 50% respectively. The nitrification process occurred consistently throughout the operation. The above averaged percentages removal are similar to what was accomplished by Matsumoto *et al.* (2007).

The results of the analysis for COD, NH_3-N, NO_3-N and P in the effluent from the Phase I operation showed a direct reduction in COD concentrations as the initial readings of raw samples were 1655 mg L^{-1} and after a six week period the treated COD reached an average of 220 mg L^{-1}. Initial average concentration of total phosphorus (P) measured from raw samples were 50 mg L^{-1}. This value reached an average of 36 mg L^{-1} after six weeks as treated samples in phase I. On the other hand, the average concentrations of NH_3-N and NO_3-N were reduced from (55 and 27 mg L^{-1}) to (32 and 2.0 mg L^{-1}), respectively as shown in Fig. 2a-d.

The COD concentration in phase two (Phase II) to the trickling filters reached 930 mg L^{-1}. The final filter effluent COD was as low as 62 mg L^{-1}, which represented over 90% removal. Although effluent ammonia tests during this stage were inconsistent. Meanwhile, the removal at weeks 2 and 7 was approximately 80%. There was no

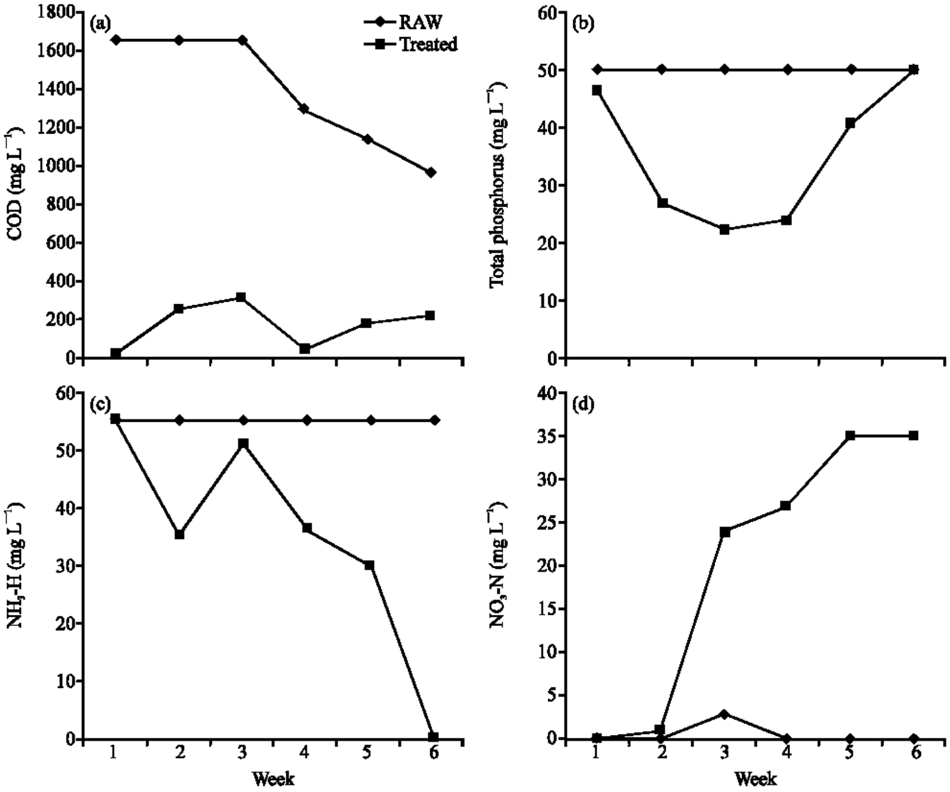

Fig. 2: Raw and treated concentrations for phase I. (a) Chemical oxygen demand-phase I, (b) Total phosphorus-phase I, (c) Ammonia nitrogen-phase I and (d) Nitrate nitrogen-phase I

sludge wasting required during both phases of the investigation. Sludge sloughing into the clarifiers was very minimal.

The effect of the septic tank upset during Phase two (Phase II) was noticeable in the lab as well as through the inconsistency and fluctuation in the concentrations of different elements as shown in Fig. 3a-d. The results of the analysis for COD, NH_3-N, NO_3-N and P for the Phase II testing period showed further reduction in the concentration of measured elements in comparison to the concentration of the raw wastewater samples. The first phase of treated samples of COD, NH_3-N, NO_3-N and P concentrations were reduced in Phase II to reach an average of 178, 20.50, 4.6 and 30 mg L^{-1}, respectively after an eight week period as shown in Fig. 3. There was no sludge wasting required during both phases of the investigation. Sludge sloughing into the clarifiers was very minimal.

Chemical loading rates are expressed as g/m^2/day and liquid loading rate is presented as L/m^2/day as shown in Fig. 4. The COD loading rate averaged 9.6 g/m^2/day within a range of (4.61-15.78) g/m^2/day, NH_3-N loading rate averaged 0.49 g/m^2/day within a range of (0.15-0.92) g/m^2/day. Meanwhile, the phosphorus loading averaged 0.45 g/m^2/day with a range of (0.14-0.84) g/m^2/day and flow loading rate averaged 9 L/m^2/day within a range of (2.79-16.75) g/m^2/day.

This laboratory scale treatment system consistently achieved 81% COD removal, 40% NH_3-N removal and 50% phosphorus removal using a single stage trickling filter following a septic tank treatment process with a COD effluent concentration ranging from 1000-1600 mg L^{-1}. These removals are significant considering the high levels of COD that were in the filter influent. Also, the phosphorus removal was higher than the researchers had anticipated for a single state trickling filter. The two-stage filter system was able to achieve 90% COD removal, as high as 80% ammonia removal and phosphorus removal of approximately 40%. Nitrate production was very consistent during the two-stage filter operation. The percentage of reductions level during phase two for COD, ammonia, phosphorus and nitrate is in full agreement with what was accomplished by Piet *et al.* (1994), Terada *et al.* (2003) and Ahn *et al.* (2003).

Phase II trickling filter operation represented by the entire conceptual sketch in Fig. 1 shows the entire

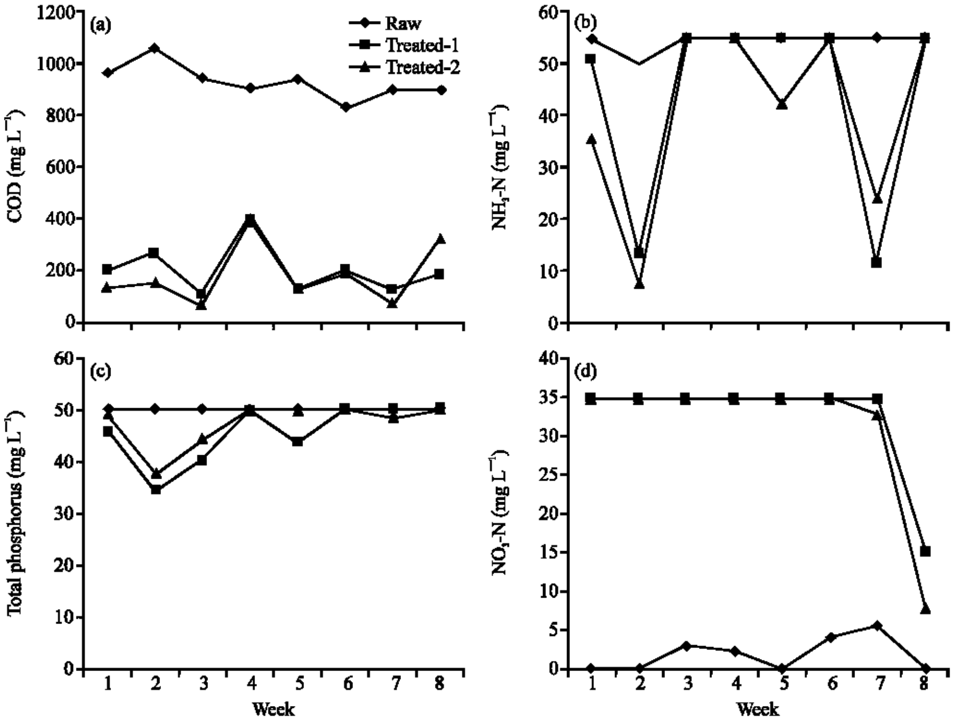

Fig. 3: Raw and treated concentrations for phase II. (a) Chemical oxygen demand-phase I, (b) Total phosphorus-phase I, (c) Ammonia nitrogen-phase I and (d) Nitrate nitrogen-phase I

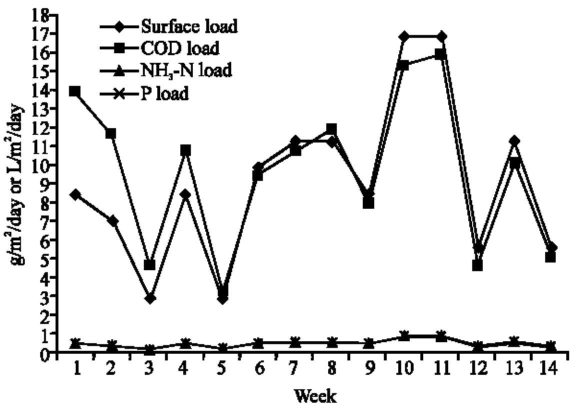

Fig. 4: Average flow and chemical loading rates throughout the study

conceptual sketch. Effluent from Phase I was received by the trickling filter in Phase II in addition to the recirculation flow as shown in Fig. 1. During Phase II of the investigation, it was noticed that the septic tanks developed turbid supernatant with floating sludge. This made withdrawal of low total suspended solids for dosing from the two stage trickling filter difficult to obtain.

The final nitrate test results showed consistent production of nitrate in the final trickling filter effluent of both filters through the final week of the investigation. The Phase II total phosphorus removal approached 40% early in the investigation and decreased after that as shown in Fig. 3. These results indicate that COD, NH_3-N and P removals can be significantly improved by addition of a single stage trickling filter system after septic tank treatment. The filter was shown to produce minimal sludge after 7 months of operation, which indicates that a full-scale system could be operated with minimal annual sludge removal from the trickling filter at the same time that the septic tanks only need pumped approximately every other year.

The two stage filter results are very promising and further long-term investigation should be conducted to quantify the functioning of the system. The investigators believe that better quantitative results may be possible with more consistent feed concentration and hydraulic operations.

Previous research has concluded that 2.5 g/m^2/day is a maximum COD loading to maintain nitrification. COD loadings for this study were consistently over that value and were as high as 9.6 g/m^2/day. Although previous studies have relied on the addition of ferrous salts for chemical precipitation of phosphorus, this study was able to achieve 50% biological phosphorus removal with minimal sludge production. Granted the phosphorus is still contained in the biomass and eventual sloughing may generate the need for some sludge disposal. However, from a rural community perspective, the biological sludge would be a better soil amendment for utilization of the phosphorus content then the current practice of using metal salts for sludge formation. Additionally, seven months of operation (3 months single stage, 4 months dual stage) produced minimal sludge in this investigation. Further, there was no clogging of the trickling filters in this operation as has been shown to occur in submerged filters requiring backwashing and a restabilization period every month or two.

CONCLUSIONS

This type of integrated system shows great promise for robust, low cost treatment operations and needs to be investigated and quantified at pilot scale for the single stage and dual stage trickling filter. Not withstanding the low sludge production for both single and dual stage operation, the intermediate clarifier concept is essential for insuring that the influent to the secondary filter is very low in suspended solids. The clogging of filters in previous studies has been linked to the introduction of flocculating solids from the activated sludge process to the submerged filter. The process investigated in this research did not rely on the activated sludge process for the influent to the filter. Under good operation, the effluent from the STEP/STEG process is very low in suspended solids and lowers the occurrence of plugging in the trickling filter. Further investigation at the pilot scale of the phosphorus removal potential under different loading scenarios without the reliance on chemical precipitation is being initiated in the sanitary engineering laboratory at Mutah University, Jordan.

ACKNOWLEDGMENTS

The authors would like to thank Ohio State University/Research Foundation-Water Resources Center for supporting this research through a grant number 739777. Laboratory analysis was completed in the Environmental Engineering Laboratory at Ohio Northern University. Additionally, we thank Derek Heckler and Drew Glover for their assistance in sampling and laboratory analysis.

REFERENCES

Ahn, K.H., K.G. Song, E. Choa, J. Cho, H. Yun, S. Lee and J. Me, 2003. Enhanced biological phosphorus and nitrogen removal using a sequencing anoxic/anaerobic membrane bioreactor (SAM) process. Desalination, 157: 345-352.

Boom, S., F.P. Huibers and J.B. van Lier, 2008. Wastewater irrigation in Jordan: A mismatch in macro nutrient provision. Water Practice Technol. DOI: 10.2166/wpt.2008.042

Borregaard, V.R., 1997. Experience with nutrient removal in fixed-film system at full scale wastewater treatment plants. Water Sci. Technol., 36: 129-137.

Canziani, R., R. Vismara, D. Basilico and L. Zinni, 1999. Nitrogen removal in fixed-bed submerged biofilters without backwashing. Water Sci. Technol., 40: 145-152.

Cortez, S., P. Teixeira, R. Oliveira and M. Mota, 2008. Rotating biological contactors: A review on main factors affecting performance. Rev. Environ. Sci. Technol., 7: 155-172.

Crites, R. and G. Tchobanoglous, 1998. Small and Decentralized Wastewater Managemant Systems. 1st Edn., WCB/McGraw Hill, New York.

Crites, R., 2007. Decentralized treatment and distributed reuse in rural communities. Proceedings of Water Environment Federation, (WEF'2007), WEFTEC., pp: 7791-7801.

FAO., 1999. Information System on Water and Agriculture. FAO., USA.

Galvez, J.M., M.A. Gomez, E. Hontoria and J. Gonzalez-Lopez, 2003. Influence of hydraulic loading and air flow rate on urban wastewater nitrogen removal with a submerged fixed-film reactor. J. Hazard Mater., 101: 219-229.

Grady, Jr. C.P.L., G.T. Daigger and H.C. Lim, 1999. Biological Wastewater Treatment. 2nd Edn., Marcel Dekker, Inc., New York, pp: 1076.

Hibiya, K., A. Terada, S. Tsuneda and A. Hirata, 2003. Simultaneous nitrificaation and denitrification by controlling vertical and horizontal microenvironments in a membrane aerated biofilm reactor. J. Biotechnol., 100: 23-32.

Hiras, D.N., I.D. Manaariots and S.G. Grigorpoulos, 2004. Organic and nitrogen removal in two-stage rotating biological contactor treating municipal wastewater. Bioresour. Technol., 93: 91-98.

Johnson, L., P. Elzbieta and B. Hultman, 1997. Experiences of nitrogen and phosphorus removal in deep-bed filters in the Stockholm area. Water Sci. Technol., 36: 183-190.

Lei, G., B. QI and Z. Wang, 2009. Treatment of municipal sewage by Biological Aerated Filter (BAF) using burned clay pellet as media. Int. J. Environ. Pollut., 37: 186-204.

Matsumoto, S., A. Terada and S. Tsuneda, 2007. Modeling of membrane-aerated biofilm: Effects of C/N ratio, biofilm thickness and surface loading of oxygen on feasibility of simultaneous nitrification and denitrification. Biochem. Eng. J., 37: 98-107.

Menoud, P., C.H. Wong, H.A. Roninson, A. Farquhar, J.P. Barford and G.W. Barton, 1999. Simultaneous nitrification and denitrification using siporax packing. Water Sci. Technol., 40: 153-160.

Morgan, S., R. Farley and B. Pearson, 1999. Retrofitting an existing trickling filter plant to BNR Standard-Self's Point, Tasmania's First. Water Sci. Technol., 39: 143-150.

Nowak, O., 2000. Upgrading of wastewater treatment plants equipped with rotating biological contactors to nitrification and P removal. Water Sci. Technol., 41: 145-153.

Nyhuis, G., 1990. Enlargement of sewage treatment plants for nitrification by use of subsequent rotating biological contactors. Water Sci. Technol., 22: 161-168.

Ong, S.L., J.Y. Hu, L.Y. Lee, W.J. Ng and L.F. Song, 2002. Packed bed columns for high rate nitrogen and carbon removals. Water Sci. Technol., 46: 57-62.

Ong, S.L., L.Y. Lee, J.Y. Hu and W.J. Ng, 2003. Nitrogen removal using combined ultracompact biofilm reactor-packed bed system. J. Environ. Eng., 129: 43-51.

Pierce, J.J., R.F. Weiner and P.A. Vesilind, 1994. Environmental Pollution and Control. 4th Edn., Butterworth-Heinemann, Boston.

Piet, N.L., M.V. Piet, S. Lode and H.V. Willy, 1994. Direct treatment of domestic wastewater by percolation over peat, bark and wood chips. Water Res., 28: 17-26.

Salvato, J.A., 1955. Experience with subsurface sand filters. Sewage Ind. Wastes, 27: 809-916.

Sauer, D.K., 1977. Treatment systems required for surface discharge of onsite wastewater. Proceedings of 3rd National Conference for Individual Onsite Wastewater Systems, (NCIOWS'77), Ann Arbor, Michigan, pp: 113-129.

Terada, A., K. Hibiya, J. Nagai, S. Tsuneda and A. Hirata, 2003. Nitrogen removal characteristics and biofilm analysis of a membrane-aerated biofilm reactor applicable to high-strength nitrogenous wastewater treatment. J. Biosci. Bioeng., 95: 170-178.

USEPA., 2000. Sanitary Sewer Overflows. USEPA., United State.