Trickling filters: Alternative for Ammonia Removal from Stabilization Pond System Effluent

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Abstract Two aerobic trickling filters were employed to nitrify the facultative, photosynhtetic pond effluent. One of them was filled with crushed rock no.4 (specific area 50 to 70 $m^{-2}.m^{-3}$) whereas the other biofilter was filled with plastic rings (specific area 80 $m^{-2}.m^{-3}$). In this way it was possible to remove ammonia nitrogen (N) so as to obtain average ammonia N concentrations of 7,9 $mgN.L^{-1}$ in the crushed rock no. 4 biofilter effluent and 15 $mgN.L^{-1}$ in the plastic ring biofilter in Phase 1 (volumetric loading rate of up to 0.55 $kgTKN.m^{-3}.day^{-1}$ and hydraulic loading rate of up to 6.0 $m^3.m^{-2}.day^{-1}$ for both biofilters). In Phase 2 (volumetric loading rate up to 0.11 $kgTKN.m^{-3}.day^{-1}$ and hydraulic loading rate up to 9.0 $m^3.m^{-2}.day^{-1}$ for the crushed rock no. 4 biofilter; volumetric loading rate up to 0.08 $kgTKN.m^{-3}.day^{-1}$ and hydraulic loading rate up to 8.0 $m^3.m^{-2}.day^{-1}$ for the plastic ring biofilter), the average ammonia N concentrations were 12 $mgN.L^{-1}$ in the crushed rock no. 4 biofilter and 16 $mgN.L^{-1}$ in the plastic ring biofilter. In Phase 3 (volumetric loading rates up to 0.15 and 0.17 kg $TKN.m^3.day^{-1}$ and hydraulic loading rates up to 12.0 and 8.0 $m^3.m^{-2}.d^{-1}$ in the crushed rock no. 4 and plastic ring biofilters, respectively), the average ammonia N concentrations were 17 $mgN.L^{-1}$ in the crushed rock no. 4 biofilter effluent and 15 $mgN.L^{-1}$ in the plastic ring biofilter effluent. With regard to all three experimental Phases, the average influent ammonia N concentration was 35 $mgN.L^{-1}$. Nitrification was observed in all three Phases, with high nitrite and nitrate concentrations.
Keywords: trickling filters, facultative pond, nitrification; ammonia removal.

INTRODUCTION

Stabilization Pond Systemas are extensively employed in Brazil to treat sanitary sewage from small municipalities. In several regions in Brazil the dilution of sewage discharges by natural water bodies is compromised during dry weather periods, rrsulting in serous difficulties to meet the discharge limits for ammonia nitrogen (N). This work looked into ammonia N removal from facultative pond effluent by means of trickling filters. Specifically speaking, the main goal was to establish the biofilters´ ammonia nitrogen removal capability in association with the loading rate. The effects of other operational conditions such as pH, temperature and dissolved oxygen (DO) concentration were evaluated. Further, an understanding of the ammonia removal mechanisms and their relative importances were sought.

One of the major theoretical references for this study was the work by Pressinotti (2003), who operated a trickling filters under controlled temperature at 25°C in Germany, with settled sewage as feed. Other authors such as Anthonissen (1976) e Metcalf & Eddy (2002) reported on nitrification capabilities of attached growth bioreactors. In our case study, it is believed that the facultative pond effluent is adequate to receive the trickling filters post-treatment, since the DO concentrations were high (at least during the day), pH values were around 8.0 and the average temperature was at 25°C; besides, the soluble carbonaceous biodegradabvel organic matter concentrations were low. Therefore, in case the aplication of a relatively high loading rate to the biofilters were possible and the biofilters´effluent presented enough ammonia concentrations in their effluents, such alternative then could be recommended for plenty of situations in which the existing pondind system is unable to meet the legal limits for ammonia nitrogen and also there is not avaliavble land in which to build tertiary ponds.

MATERIALS AND METHODS

The field work was conducted at SABESP´s experimental station in Lins,SP, Brazil. There are three treatment modules in parallel – each one composed of one anaerobic pond followed by a facultative pond – treating the sanitary sewage from the municipality, representing approximately 65,000 inhabitants. The anaerobic and facultative ponds are operated at the following conditions, respectively: effective depths: 4.1 and 1.9 m; surface areas: 6,827 m^2 and 31,469 m^2; effective volumes: 23,227 m^3 and 55,529 m^3; detention times: 5.8 days and 13.9 days; surface BOD loading rates: 1,471 kg/ha.day and160 kg/ha.day;volumetric BOD loading rates: 0.043 kg/m^3.day and 0.009 kg/m^3.day.

Both biofilters were built as a single cylindrical body (1,2 m inner diameter) made of polypropelene, with a vertical plate inside which divided the body into two compartments with same volume. One compartment was filled with crushed rock no. 4 (specific area in the range 50 to 70 $m^2.m^{-3}$) and the other was filled with plastic rings (120 $m^2.m^{-3}$), so that the effect of support media was investigated. The media height was 4 m. The total surface area (the two biofilters) was 1.13 m^2 and the total effective volume was 4.52 m^3. The available surface area for biofilm formation was about 316.7 m^2 in the crushed rock no. 4 biofilter and about 542.9 m^2 in the plastic ring biofilter.

Secondary settlers were sized based on a maximum surface application rate of 30 $m^3.m^{-2}.day^{-1}$, which ressults in a surface area of 0.785 m^2 for the maximum flow rate of 23.6 $m^3.day^{-1}$. They wer built with concrete rings with 1.0 m inner diameter and effective depth of 3.0 m. The effective volume was 2.36 m^3 and the minimum hydraulic detention time was 2.4 hrs, based on the maximum flow rate.

The work also entailed the monitoring and characterization of the sanitary sewage at the inlets and outlets of the real scale anaerobic and facultative ponds. Operation of the pilot scale biofilters as post-treatment step was based on increasing flow rate feed type of operation duirng three Phases of six months each. Monitoring of the facultative pond effluent was crucial for the evaluation of the biofilters´ performance. Throughout the treatment system the following parametres were monitored: temperature, pH, total alkalinity, solids series, BOD, COD, TKN, ammonia N, nitrite, nitrate and total P, on a weekly basis. Sampling was done during peak influent (to the ponding system) flow rate times. Some sampling was done for 24-hour, composite samples.

RESULTS AND DISCUSSION

Trickling filters operation in Phase 1

Both biofilters were started out on 6/18/2007,with facultative pond effluent feed. The volumetric TKN load was 0.025 $kgTKN.m^{-3}.day^{-1}$ and the hydraulic loading rate was 4.2 $m^3.m^{-2}.day^{-1}$, after acclimatization period of about 100 days. Figure 1 depicts the operational conditions.

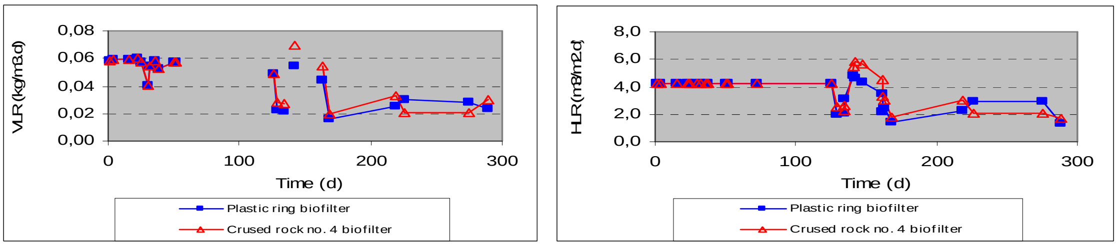


Figure 1: Volumetric TKN Loading Rate and Hydraulic Loading Rate (1rst Phase)

It can be observed that the volumetric and hydraulic loading rates reached 0.55 kg NKT.m^{-3}.day^{-1} and 6.0 m^{3}.m^{2}.day^{-1}, respectively.

Figure 2 shows pH, total alkalinity, temperature and DO concentration in the effluents. High temperature and pH conditions were observed; they favor nitrification. The larger consumption of alkalinity in the crushed rock no. 4 biofilter indicated higher degree of nitrification.

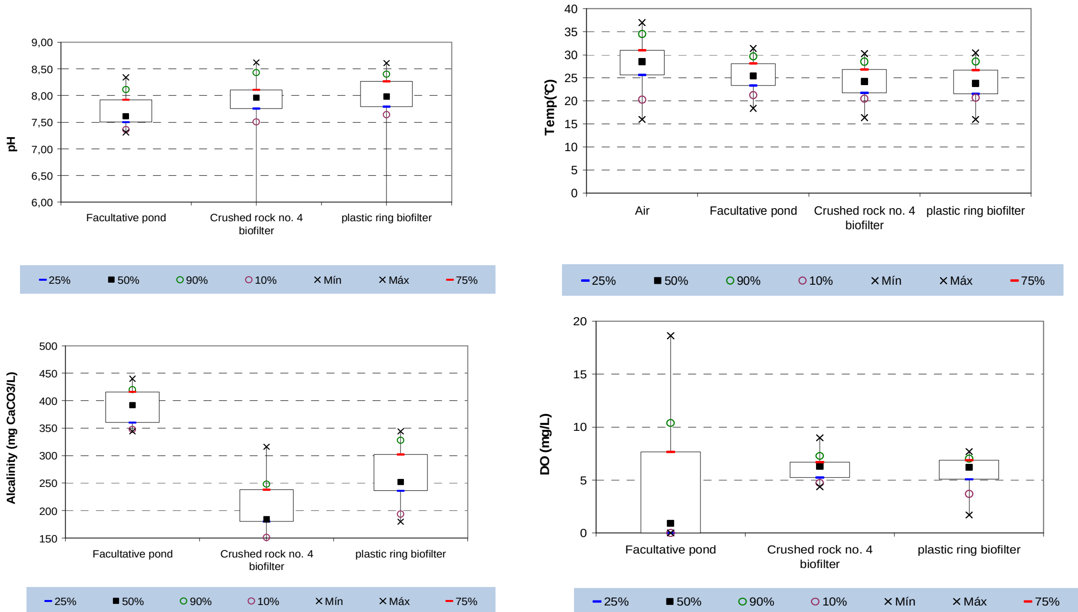
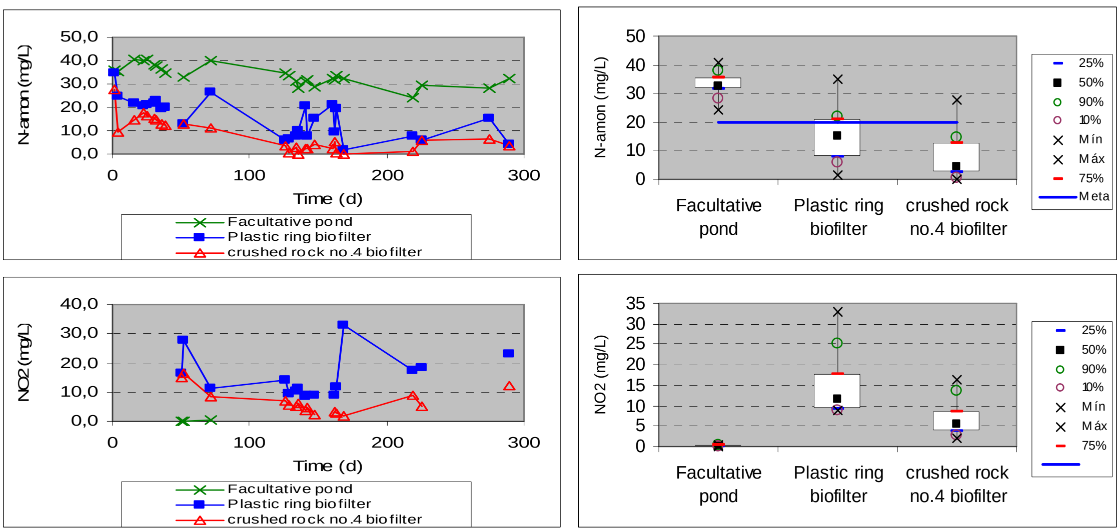


Figure 2: Control parameter results: pH, temperature, alkalinity and DO (1rst Phase)

Figure 3 depicts the monitoring results of the nitrogen species.



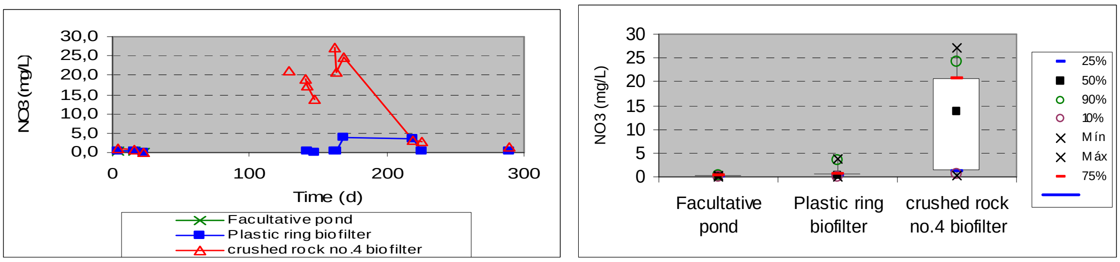


Figure 3: Data Series and Box-whisker Diagrams: Nitrogen Species (1rst Phase)

For the operating conditions imposed in this experimental phase, both biofilters reduced the ammonia N concentrations below the legal standard (20 mg/L). Biofilter evolution was faster for the crushed rock no. 4 biofilter than for the plastic ring biofilter. The former currently presents practically complete nitrification. Nitrite accumulation was noticeable particularly in the plastic ring biofilter At pH = 8,0 and high DO concentrations during day time, nitritation was inhibited.

Regarding organic matter removal, Figure 4 shows effluent COD and BOD.

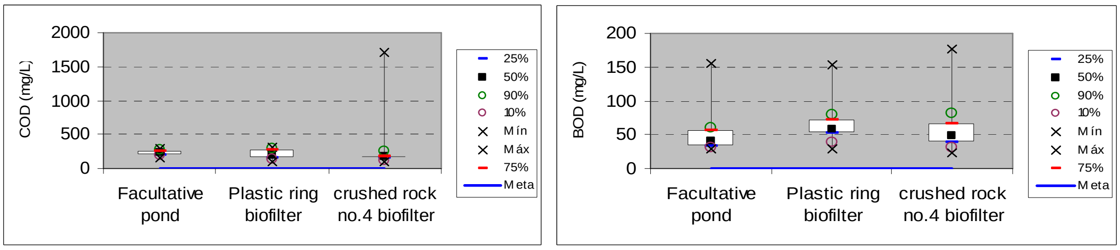


Figure 4: Effluent COD and BOD Concentrations (1rst Phase)

The biofilters practically did not contribute with organic matter removal; this fact indicates that the biofilms in them were essentially composed by N-bacteria.

Figure 5 depicts monitoring diagrams for suspended solids and soluble phosphorus in the effluents.

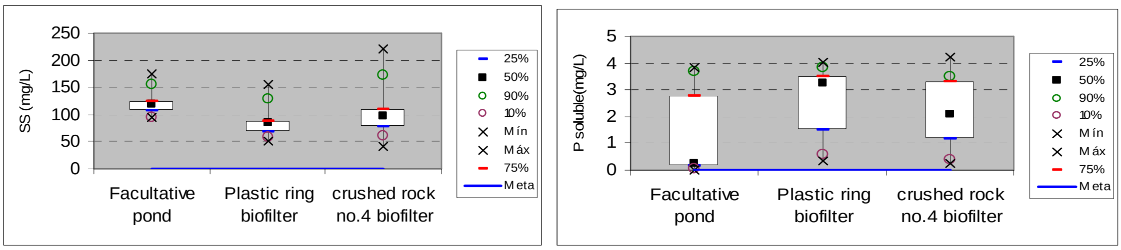


Figure 5: Suspended Solids and Soluble Phosphorus in Effluents (1rst Phase)

It was observed that, likewise in the case of organic matter removal by the biofilters, they did not contribute with either suspended solids removal or total P removal.

Trickling filters operation in Phase 2

The crushed rock no.4 and plastic ring biofilters were fed with facultative pond effluent under the following conditions, respectively: volumetric TKN loading rates of 0.063 and 0.051 kg.m^{-3}.day^{-1} and hydraulic loading rates of 4.9 and 4.0 m^{3}.m^{-2}.day^{-1}. Na Figure 6 shows the operating conditions with time.

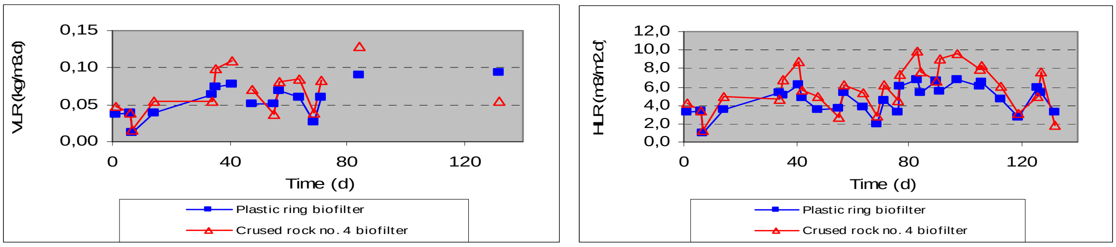


Figure 6: Volumetric TKN Loading Rates and Hydraulic Loading Rates (2nd Phase)

It is noted that the crushed rock biofilter was fed up to 0.13 kgTKN.m^{-3}.day^{-1} with a HLR up to 9.0 m^{3}.m^{-2}.day^{-1}, whereas the plastic ring biofilter was fed up to 0.08 kgTKN.m^{-3}.day^{-1} with a HLR up to 8.0 m^{3}.m^{-2}.day^{-1}, higher rates than in Phase 1.

Figure 7 depicts process control variables: pH, alkalinity, temperature and DO concentration in the effluents. pH, temperature and DO conditions that were favorable to nitrification were observed; such conditions led to consumption of alkalinity from the facultative pond effluent that fed the biofilters.

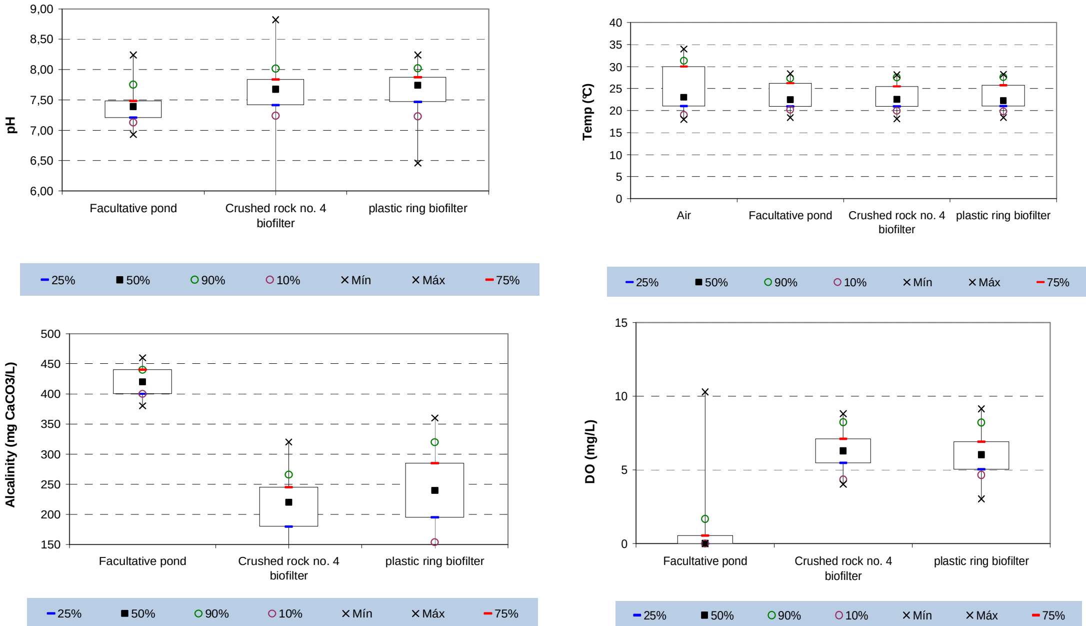


Figure 7: Process Control Variables: pH, temperature, alkalinity and DO (2nd Phase).

In Figure 8 are shown the historic data series of all the nitrogen species. The reduction in the ammonia N concentration was greater in the crushed rock no.4 biofilter. However there was nitrite accumulation in both biofilters, in the same fashion as in the first few months of operation in Phase 1, thus indicating that there was inhibition of nitritation. One suspects that the nitrate concentration numbers are possibly incorrect due to analytical problems which resulted from saturation of the cadmium column. The troubled column was replaced. The nitrate concentrations in the final effluent increased in the next Phase. Although nitrite accumulation continued to take place, a nitrification balance demonstrated convergence, in a way to assure that the volatilization effect was of small importance.

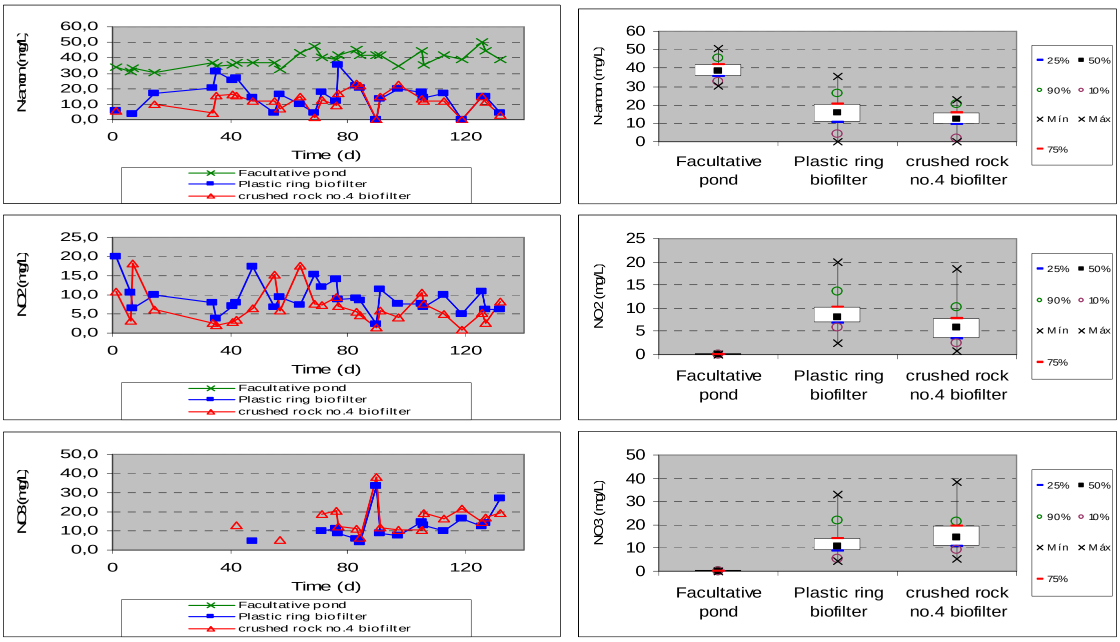


Figure 8: Historical Data Series and Box-whisker Diagrams, N species (2nd Phase)

Percolating Biofilter Operation in Phase 3

Both biofilters received facultative pond effluent under the following conditions: volumetric TKN loading rates of 0.095 and 0.077 kg.m^{-3}.day^{-1} and hydraulic loading rates of 7.4 e 6.0 m^{3}.m^{-2}.day^{-1}. Figure 9 shows the imposed operating conditions.

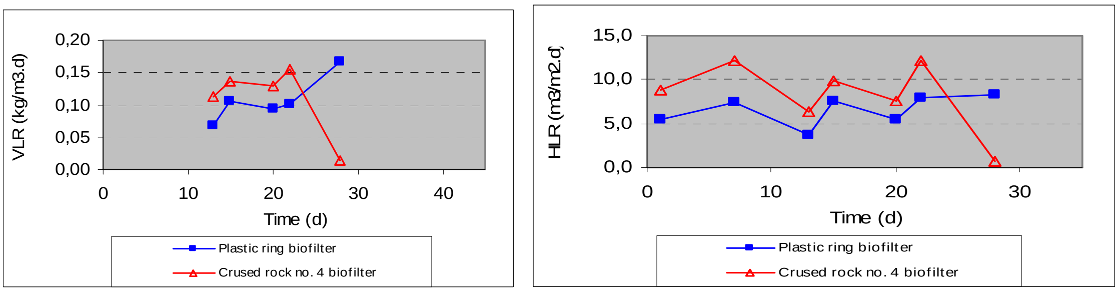
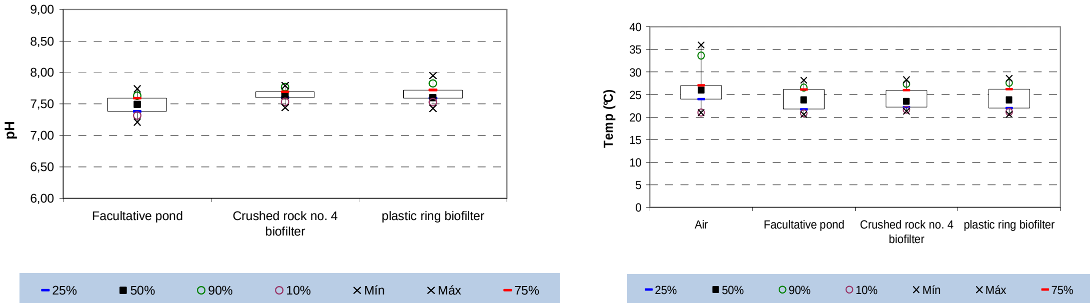


Figure 9: Volumetric TKN and Hydraulic Loading Rates for the Biofilters (3rd Phase).

It is noted that the volumetric loading rates reached 0.15 and 0.17 kg TKN.m^{3}.day^{-1} and the hydraulic loading rates reached 12.0 and 8.0 m^{3}.m^{-2}.day^{-1} in the crushed rock no. 4 and plastic ring biofilters, respectively. Figure 10 depicts control variable results: pH, alkalinity, temperature and the DO concentration in the effluents. It can be inferred that the temperature, pH and DO concentration values were favorable to nitrification, which entailed alkalinity consumption from the biofilter feed, the facultative pond effluent. The consumption of alkalinity can be considered a confirmation of nitrification.



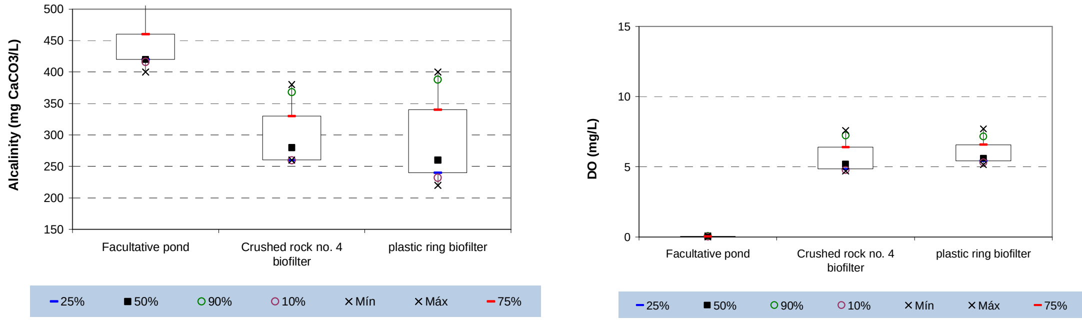


Figure 10: pH, Temperature, Alkalinity and DO Control Results (3rd Phase)

These results were plotted as historical data series and as box-whisker diagrams in Figure 11. It can be inferred that the reduction in ammonia N concentration took place in a similar manner in both biofilters, thus indicating the recovery of the plastic ring biofilter. Accumulation of a certain fraction of nitrite happened again, thus such occcurences can be practically consided as definitive. The pH range of the facultative pond effluent appears to be the main mechanism that led to the partial inhibition of nitritation in the reactors.

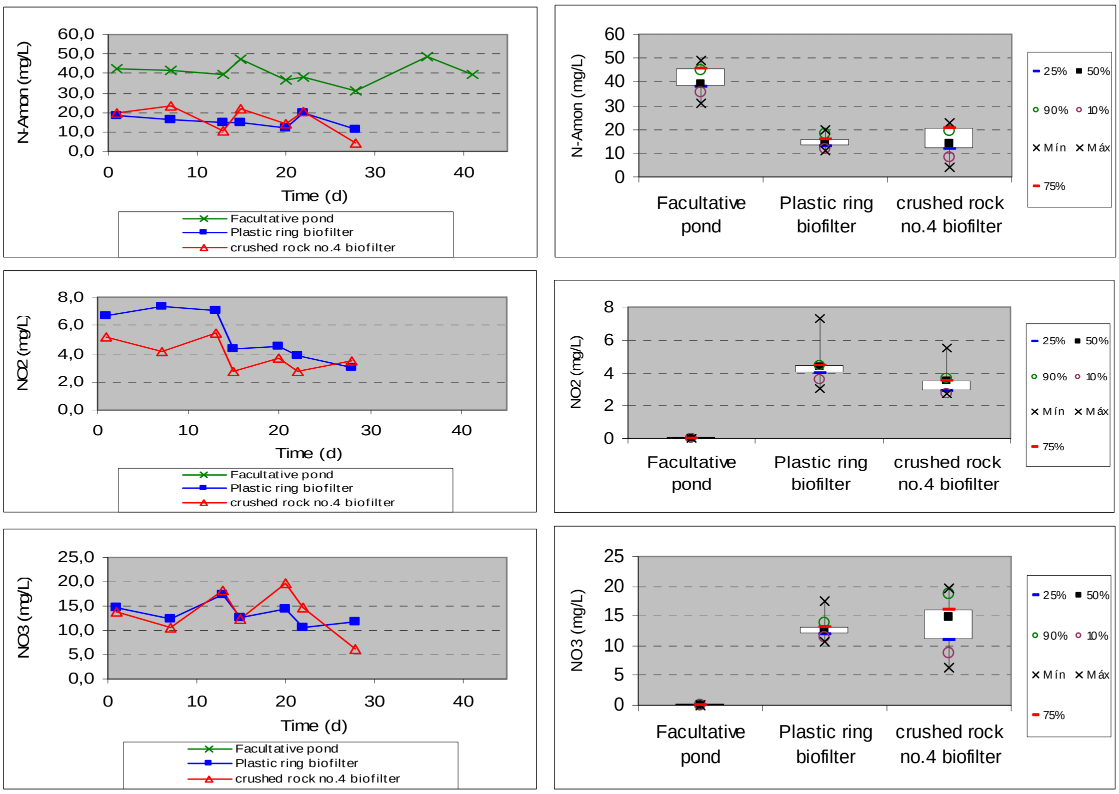
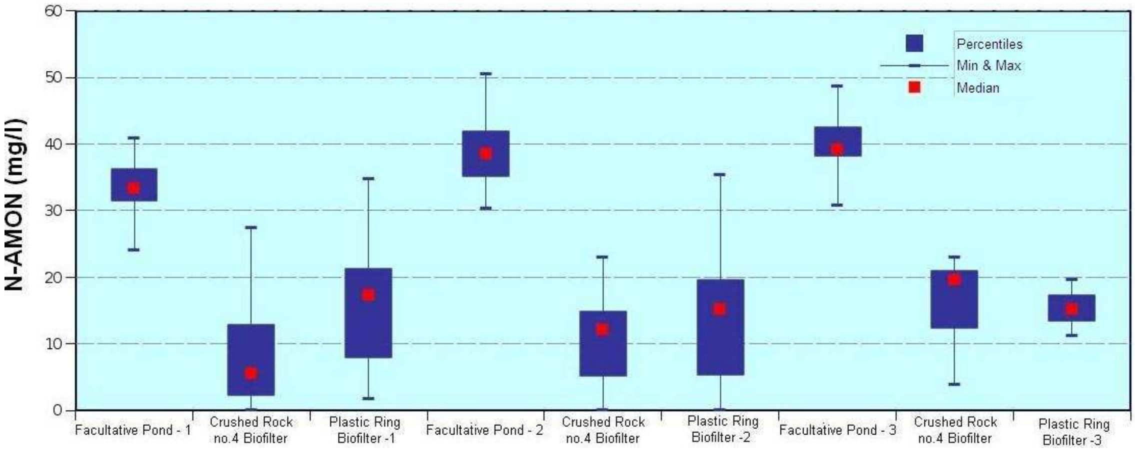


Figure 11: Historical Data Series and Box-whisker Diagrams, N Species (3rd Phase)

In Figure 12 the results from all three experimental phases are shown for comparison purposes. The results demonstrated that the increase in the application rates led to a reduction in the ammonia nitrogen removal efficiency; on the other hand, the effluents presented ammonia concentrations below the reference value, 20 mgN.L^{-1}. The results also showed the slower evolution of the plastic ring biofilter as compared to the crushed rock no. 4 biofilter.

Figure 12: Comparison of the Three Experimental Phases



CONCLUSIONS

The experimental results demonstrated that aerobic trickling filters allow for nitrification of the facultative pond effluent. Special attention must be given to the possible occurrence of ammonium ion oxidation to nitrite only.

Total or partial nitrification was confirmed in Phase 3 by means of determinations of the densities of nitritating and nitratating bacteria, as well the nitrite and nitrate ion productions and alkalinity consumption.

In Phase 3 the volumetric loading rates reached 0.15 and 0.17 kg TKN.m^3.day^{-1} and the hydraulic surface loading rates reached 12.0 and 8.0 m^3.m^{-2}.day^{-1} in the crushed rock no. 4 and plastic ring biofilters, respectively, without any discernible, irreversible drawbacks to them.

The biofilm formed onto the percolating media appeared to be selective, in view of the occurrence of nitrification without any significant additional BOD removal. Thus nitrifying bacteria did predominate, without significant presence of heterotrophic bacteria. Biofilm development onto the plastic media (plastic rings) appeared slower than biofilm development in the crushed rock no. 4 biofilter, probably as a function of a lower roughness of the plastic media as compared to the crushed rock no.4 media.

The pH and temperature conditions as well as the high DO concentrations in the facultative pond effluent were favorable to the nitrification process; sudden drops in those numbers during the night time might have cause interruption of nitratation or denitrification via nitrite; such hypothesis deserves to be thoroughly investigated.

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