PERFORMANCE AND RELIABILITY ANALYSIS OF ANAEROBIC/ANOXIC AND AEROBIC COMPARTMENTED REACTORS TREATING DILUTED DOMESTIC SEWAGE

Juliana Morais[1], Kenia K. Barros[2*], Fabrício Montteran[3], Lourdinha Florencio[3] & Mario T. Kato[3]

[1] Department of Infrastructure and Civil Construction, Federal Institute of Pernambuco, Recife, Brazil.
[2] Laboratory of Environmental Engineering, Technology Center/Academic Center of Agreste, Federal University of Pernambuco, Caruaru, Brazil.
[3] Laboratory of Environmental Sanitation, Environmental and Civil Engineering Department/Technology Center, Federal University of Pernambuco, Recife, Brazil
** Corresponding author's email address: kenia.barros@ufpe.br*

ABSTRACT

Two vertical compartmented reactors were employed for treating low-strength domestic sewage, each consisting of anaerobic/anoxic and aerobic compartments with hydraulic retention times (HRTs) of 8 to 12 hours. The first and second reactors had recirculation ratios of 1.5 and 3.0, respectively. Nitrified effluent from the aerobic compartment was recirculated to the anaerobic compartment without an extra electron donor. The optimal results were obtained with a 12-hour HRT for both reactors. Reactor 1 achieved average removal efficiencies of 52% ± 15%, 81% ± 7%, and 60% ± 12% for total chemical oxygen demand (total COD), filtered COD, and N-TKN, respectively. Reactor 2 showed removal efficiencies of 51% ± 15%, 83% ± 6%, and 57% ± 11%. It is worth mentioning that the reactor configuration did not negatively impact the microbiota responsible for treatment and proved to be effective in treating diluted wastewater.

Keywords: Heterotrophic and autotrophic competition. Nitrification and denitrification. Moving Bed Biofilm Reactor (MBBR). Microbial dynamics. Reliability analysis.

1 INTRODUCTION

Decentralized wastewater treatment plants (WWTPs) are gaining increasing attention globally as cost-effective alternatives to centralized facilities. Combined anaerobic and aerobic reactors present a promising solution for domestic sewage treatment, aiming to optimize space utilization and reduce construction and operational expenses. The anaerobic process stands out in terms of organic matter removal and is complemented by the efficient nitrification of aerobic processes with lower oxygen consumption.[1] The integration of both reactor processes addresses the limitations of traditional nitrogen removal and offers versatility in handling diverse wastewater compositions.

Combined anaerobic/anoxic/aerobic reactors offer advantages such as high removal rates for organics and nutrients, adaptability to hydraulic and organic shock loads, low hydraulic retention time (HRT), space efficiency, and retrofitting ease in existing WWTPs. The presence of biofilms in moving med biofilm reactors (MBBRs) enhances their adaptability to rapid environmental changes, benefiting from diverse microbial compositions that boost pollutant removal, especially for nitrogen and phosphorus. [2] The objective of the present study was to evaluate the ability of a reactor system with anaerobic/anoxic and aerobic compartments to simultaneously remove organic matter and nitrogen from low-strength domestic wastewater under different operational conditions with different HRTs and recirculation ratios. Furthermore, a reliability analysis was undertaken on the treatment technology to assess whether the operational parameter concentrations align with the necessary reliability thresholds for the intended reactors.

2 MATERIAL & METHODS

The experimental setup consisted of two vertical compartmentalized reactors placed in parallel. The bed of each reactor was divided into two compartments of varying volumes, separated by perforated stainless steel plates. Compartment 1 was designated as anaerobic/anoxic and was primarily aimed at organic matter (MO) removal and denitrification after effluent recycling. Compartment 2, which is aerobic, promoted nitrification and removed the remaining MO.

The system underwent a comprehensive operational process spanning four distinct phases over 565 days. In the initial phase (P1), the reactors were operated with an HRT of 12 hours without effluent recycling. After system stabilization, effluent recycling was implemented in the anaerobic compartment. Subsequent phases (P2, P3, and P4) were performed with HRTs of 12, 10, and 8 hours, respectively. Reactors 1 (R1) and 2 (R2) had recycling ratios of 1.5 and 3.0, respectively. The dissolved oxygen concentration was kept constant at 2.0 mg L^{-1}.

The coefficient of reliability (COR) was used to assess the treatment processes and was calculated according to the methodology described by Niku et al.[3]. The average concentrations of each analyzed parameter in the project or operation were compared with the required standard values based on probability. Therefore, the calculation of the COR was based on the effluent's compliance with the discharge standard.

Molecular biology techniques such as polymerase chain reaction (PCR) followed by denaturing gradient gel electrophoresis (DGGE) were employed to investigate microbial diversity. The aim of this study was to characterize and assess the development of microbial populations in nitrifying and denitrifying biomass. Samples of the suspended sludge and that of the sludge attached to support media (K3 - AnoxKaldnes®) were collected at the end of P1, P2 and P3. DGGE was carried out on a D-Code apparatus (Bio-Rad Laboratories, CA) with modifications to the method proposed by Muyzer et al.[4]. The universal primers (Total Bacteria – BAC 968F, BAC 1392R; Ammonium Oxidizing Bacteria – NSO 190F, NSO 1225R; Denitrifying Bacteria – nirS 2F, nirS 3R; Anammox Bacteria – AMX368F, AMX820R; Total Archaea – 1100 F, 1400 R) were used to amplify the 16S rRNA of Bacteria and the Archaea domain.

3 RESULTS & DISCUSSION

During the experiment, the temperature and pH of the influent sewage remained stable at 29.3 ± 2.4 °C and 7.3 ± 0.3, respectively. The mean concentrations of total COD (COD_T), total Kjeldahl nitrogen (TKN) and NH_4^+ were 475 ± 174, 40 ± 7 and 28 ± 3 mg N L^{-1}, respectively. The ratio of the filtrate COD (COD_F) to the COD_T was 0.42, indicating the presence of a lower fraction of dissolved organic matter. The influent total solids (TS) presented a large inert fraction with a total fixed solids (TFS)/TS ratio of 0.6, whereas the suspended fraction (TSS) was low, with a TSS/TS ratio of 0.22.

Regarding organic matter (OM) and N removal, in both reactors (reactor 1, R1, and reactor 2, R2), the anaerobic compartment showed satisfactory performance since the OM removal efficiency was above 80%, based on the effluent COD_F, while the aerobic compartment promoted nitrification. The loss of solids from the anaerobic compartment promoted a stratified biofilm in the aerobic compartment, where heterotrophic bacteria located in the outer layer of the biofilm overlapped the nitrifying bacteria located in the inner part. Since the reactors were started without inoculum in the compartments, nitrification began on days 34 and 43 in the aerobic compartments of R1 and R2, respectively. However, the nitrification process reached operational stability only after day 99 for R1 and after day 124 for R2. As nitrite (0.2 ± 0.5 mg L^{-1}) and nitrate (0.1 ± 0.1 mg L^{-1}) did not represent a significant fraction of the influent in either reactor, the average nitrate concentrations were 10.8 and 11.1 mg L^{-1} in the effluent of R1 and R2, respectively.

Distinct environmental conditions (aerobic, anoxic/anaerobic) effectively enhanced the removal of organic and ammonium nitrogen. This approach facilitated the development of ammonia-oxidizing bacteria (AOB), as indicated by PCR amplification bands within the aerobic and anoxic compartments of R1 and R2. During P1, AOB were detected in the attached sludge but absent in the suspended sludge of both compartmentalized reactors. Denitrifying bacteria were consistently identified in the aerobic compartment of all the samples analyzed from reactors operating in an anaerobic-aerobic compartment without recirculation. Nitrite concentrations in the anaerobic/anoxic compartment remained consistently low, inhibiting ammonium anaerobic oxidation due to the absence of nitrite as an electron acceptor. The most favorable results for simultaneous C and N removal were achieved in P2, with a 12-hour HRT and recycling rates of 1.5 and 3.0 for R1 and R2, respectively. Under these conditions, with an applied organic loading rate of 0.50 ± 0.15 kg.COD.m^{-3} d^{-1} in both reactors, the average COD removal efficiencies were 81% (R1) and 83% (R2), while the TKN removal efficiencies were 60% (R1) and 57% (R2).

Regarding the coefficient of reliability (COR), the mean total COD did not achieve a reliability level of 80%. The mean effluent concentration obtained (MCO) was much greater than the mean effluent concentration of the project (MCP). NH_4^+ presented MCO values close to the MCP values for a reliability level of 80%. However, the reliability of the COD_F was above 85% for the two reactors in all the operational phases. The TSS values decreased when the recirculation ratio was introduced. From P1 (r = 0) to P4 (r = 1.5 or r = 3.0), the TSS reliability decreased from 85 to 40% (R1) and 50% (R2). In P1, both reactors (R1 and R2) demonstrated high reliability (85-90%) for COD_F, TSS, and NH_4^+. However, this phase focused solely on optimizing the nitrification step by operating reactors with only anaerobic and aerobic compartments.

By DGGE analysis, 80% and 86% similarity were observed for the microbiota attached to the supporting material in compartments 1 and 2 of R1 and R2, respectively, showing that some microorganism groups were able to form biofilms and grow as aggregates. In addition, 84% similarity was observed between microorganisms suspended in the aerobic compartments of R1 and R2. When comparing the biomass attached to the supporting material of R2 with the suspended biomass of R1 in their respective aerobic compartments, a similarity of approximately 78% was observed. The similarity between the suspended biomass of R1 and R2 was 50%, indicating that some microorganisms can release themselves from the supporting material and move to other compartments. The greatest difference between the samples analyzed in P1 was found when the attached biomass in the second compartment of R1 was compared with the suspended biomass of the other compartment in R2. Only 18% similarity was found between these two samples (Figure 1).

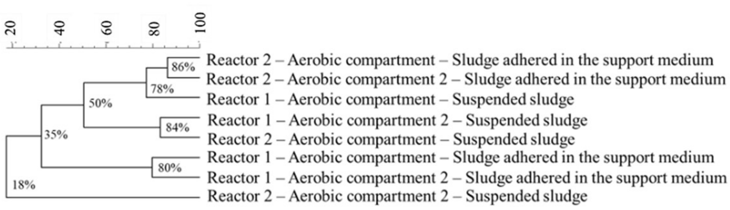

Figure 1 Dendrogram of the similarity of the DGGE band profiles of samples extracted from phase 1.

A significant resemblance was observed between the samples collected in P2 and P4, surpassing those obtained in P1. Specifically, in R1 during P2, DGGE analysis revealed 47% similarity between the suspended and attached biomass in the aerobic compartment. During P4, the similarity between R1 and R2 increased to 97%, indicating a consistent biomass composition. Both reactors R1 and R2 showed a significant increase in suspended biomass between P2 and P4. This trend highlights the increased similarity between samples collected in P2 and P4, surpassing those collected in P1. A notable 97% similarity was observed between the biomass of the aerobic compartment of R1 and that of the anaerobic compartment of R2 during P4. This high similarity is likely due to biomass removal from the biofilm in R1. The biofilm environment may impose limitations on nutrient and oxygen dispersion, potentially favoring the selection of facultative bacteria or microorganisms that survive in microaeration conditions in the anaerobic section of the reactor (Figure 2).

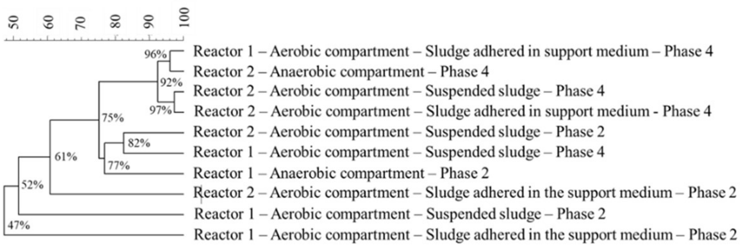

Figure 2 Dendrogram of the similarity of the DGGE band profiles of samples extracted from phases 2 and 4.

4 CONCLUSION

The findings indicate that anaerobic/anoxic-aerobic compartmented reactors present a promising alternative for organic matter and nitrogen removal. The reactors demonstrated suitable average removal efficiencies, reaching 80% for organic matter and 57% for nitrogen when operated with a 12-hour HRT and a recycling rate equal to 1.5. Significantly, the initial anaerobic compartment played a crucial role in achieving successful simultaneous removal, effectively eliminating most of the organic matter and promoting a high level of ammonification.

This initial phase proved crucial for creating favorable operational conditions inside the subsequent aerobic compartment. By significantly reducing competition between carbon-utilizing heterotrophic microorganisms and autotrophic nitrifiers, the success of the system was enhanced. The strategic recirculation of effluent further facilitated denitrification in the anaerobic/anoxic compartment without the need for an additional electron donor. This integrated approach highlights the efficiency and synergy of the compartmented reactor system, showing its potential for sustainable and effective wastewater treatment.

Regarding the reliability analysis, there was low variability among the four operational phases studied when considering coefficients of variation and reliability. Nevertheless, the results showed that compartmented reactors can provide good-quality effluent when a reliability standard of 80% is applied.

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