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USE OF A FIXED-BED REACTOR WITH BIOBOB® MEDIUM, OPERATING AT PILOT SCALE FOR REMOVAL OF COD AND TOTAL NITROGEN FROM SANITARY SEWAGE

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ABSTRACT

This study operated a pilot reactor, installed in a real municipal wastewater treatment plant. The reactor featured a packed fixed bed made of Biobob®, a high-density polyethylene structure with expanded polyurethane, with a total volume of 5.65m^3 and an effective volume of 3.20m^3, operating under upflow conditions. The reactor objective was the removal of Total Nitrogen through Simultaneous Nitrification and Denitrification, as well as COD removal. The reactor operated with intermittent aeration and HRT of 10, 12, and 20 hours. The feed consisted of substrates in ratios of 1:1 (v:v) raw sewage/UASB effluent and UASB effluent. The reactor withstood the variations in load at the WWTP, facing common challenges of large-scale systems. The E2 stage - raw sewage:UASB - stood out with an average N removal of 55% and an average COD removal of 81%. SEM images demonstrated synergy between nitrifying bacteria, denitrifying bacteria, and methanogenic archaea.

KEYWORDS: Simultaneous Nitrification and Denitrification, Intermittent Aeration, Removal of Organic Matter.

USO DE REATOR DE LEITO FIXO EM MEIO SUPORTE BIOBOB®, OPERANDO EM ESCALA PILOTO NA REMOÇÃO DE DQO E NITROGÊNIO TOTAL DE ESGOTO SANITÁRIO

RESUMO

Este trabalho operou um reator piloto, instalado em uma estação de tratamento de esgoto sanitário real. O reator contou com leito fixo empacotado de Biobob®, estrutura em polietileno de alta densidade com poliuretano expandido, volume total de 5,65m^3 e útil de 3,20m^3 e fluxo ascendente. O objetivo do reator foi a remoção de Nitrogênio Total via Nitrificação e Desnitrificação Simultânea e remoção de DQO. O reator operou com aeração intermitente e TDH de 10, 12 e 20h, a alimentação ocorreu com substratos nas razões 1:1 (v:v) esgoto bruto/efluente de UASB; e efluente do UASB. O reator suportou as variações de carga da ETE, adversidades comuns de sistemas em larga escala. A etapa E2 - alimentação bruto:UASB, se destacou com média de remoção de N de 55% e remoção média de DQO em 81%. As imagens obtidas por MEV demonstraram que houve sinergia entre bactérias nitrificantes, desnitrificantes e arqueas metanogênicas.

Palavras-chave: Nitrificação e Desnitrificação Simultânea, Aeração Intermitente, Remoção de Matéria Orgânica.

1 PRESENTATION

The new legal framework for sanitation, Federal Law No. 14026/2020, has as one of its main focuses the enhancement of the structural conditions of basic sanitation to serve the entire Brazilian population and maintain the quality of water bodies that will be a source of clean water that must meet the multiple uses necessary for humanity (TORRES, et al. 2019a). The regulations imposed by this framework alone would already be sufficient to encourage research in sanitary sewage treatment systems. However, population growth and the extensive physical space occupied by treatment plants justify research into compact units that promote simultaneous removal processes of nutrients and organic matter.

UASB (Upflow Anaerobic Sludge Blanket) reactors are widely used in sanitary sewage treatment. However, due to their anaerobic nature, this reactor model is inefficient in removing nutrients such as nitrogen. The discharge standards for nitrogen in its various forms are designated by CONAMA resolutions 357/2005 and 430/2011. Discharging nitrogen outside the established standards can lead to public health and environmental issues, such as methemoglobinemia and eutrophication (TORRES, et al. 2019b).

The reactor proposed in this study is a compact upflow reactor, with an anoxic environment that allows for simultaneous removal of carbon and nitrogen. Nitrogen is removed through a metabolic pathway known as Simultaneous Nitrification and Denitrification (SND) (POLAK, 2018).

For the SND process to occur, both aerobic environments are needed for nitrification, which converts ammoniacal nitrogen into nitrite and nitrate, and anoxic environments, where nitrate is transformed into gaseous nitrogen and released back into the environment (BARANA, et al., 2013; LOPES, et al., 2022).

Considering these simultaneous processes, a support medium that creates both oxic and anoxic environments, along with intermittent aeration, can help address the presented issue. In this regard, Biobob®, a commercial support medium with a foam structure, has been effective in providing an anoxic environment in the inner layers and an oxic environment in the outer layers (POLAK, 2018; OLIVEIRA, 2020; STOLLE, 2022).

In light of the presented justifications, this study aimed to assess the removal of nitrogen and COD from raw sewage and UASB effluent in a pilot-scale packed bed reactor filled with Biobob®, operating with intermittent aeration.

2 METHODOLOGY

The experiment was conducted under the coordination of UEPG in partnership with SANEPAR (Sewerage Company of Paraná), which facilitated the implementation of the pilot-scale reactor at the IAPÓ WWTP (Wastewater Treatment Plant), located in the city of Castro-PR. Additionally, the company Bioproj Tecnologia Ambiental, the developer of the support medium Biobob®, was involved in immobilizing biomass within the reactor.

The experimental setup consists of two sedimentation tanks followed by an equalization tank, and subsequently, a reactor.

The sedimentation tanks are installed in sequence. Each one has a volume of 0.8 m^3 and receives the raw sewage that has passed through the screening and grit removal stages. After passing through these two tanks, the sewage proceeds to the surge tank.

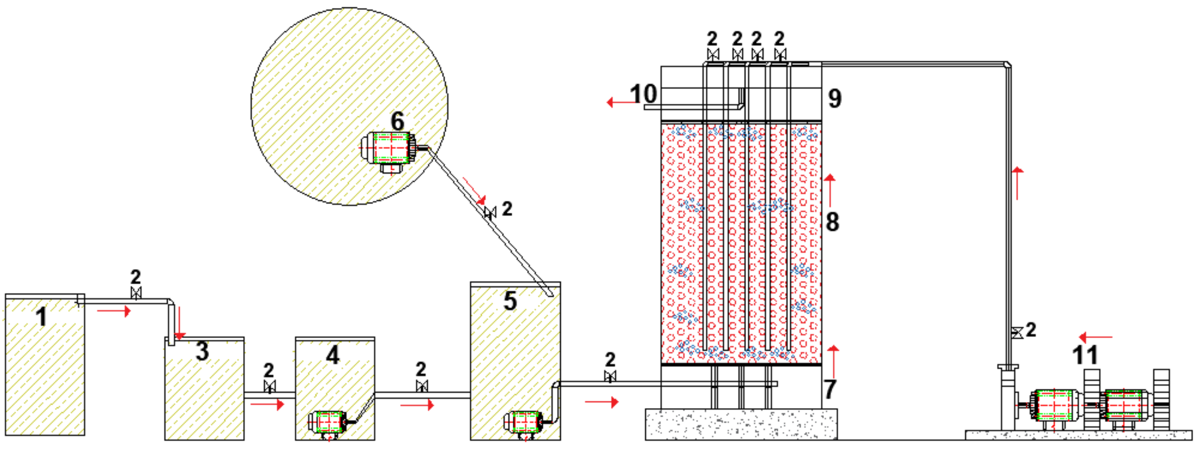
The lung tank has a volume of 1.0 m^3 and receives effluent from the RALF and sewage from the sedimentation tank at equal flow rates. This tank is equipped with a submersible semi-open rotor Sulzer grinder pump, Piranha model 08/2, with a flow capacity of up to 7.5 m^3.h-1, responsible for feeding the reactor.

The lung tank has a volume of 1.0 m^3 and receives effluent from the RALF and sewage from the sedimentation tank at equal flow rates. This tank is equipped with a Sulzer Piranha 08/2 submersible grinder pump with a semi-open rotor, capable of a flow capacity of up to 7.5 m^3.h-1, responsible for feeding the reactor.

The reactor was constructed in cylindrical fiberglass. It has a total volume of 5.65 m^3, a diameter of 1.5 m, and a height of 3.2 m, divided into three compartments: (i) mixing bed, (ii) Biobob® bed, and (iii) effluent outlet. The reactor's aeration system consists of two series-operating air blowers from the Aeromack brand, CRE-03 model, with an airflow rate in the range of 3.2 m^3.m-1 and a static pressure of 2.20 MCA. The blowers are connected to a timer that allows intermittent air intake into the lower portion of the reactor.

The Biobob® used as a support medium for the growth of microbial biomass consists of a polyurethane foam enclosed in a hollow structure made of high-density polyethylene, with a cylindrical geometry measuring 45 mm in diameter, 60 mm in height, 90% porosity, and a unit dry mass of 12 g.

The pilot reactor setup is illustrated in Figure 1.



Legend: 1 - Parshall Flume (raw tributary collection point); 2 - Globe-type regulating valve; 3 - Grit chamber tank 1 for the raw influent; 4 - Grit chamber tank 2 for the raw influent; 5 - Surge tank (equalization of raw mixture/UASB); 6 - UASB Reactor (collection point for the second influent of the mixture); 7 - Upflow Mixed Bed; 8 - Polyurethane foam bed structured on plastic support (Biobob®); 9 - Outlet chamber; 10 - Effluent discharge; 11 - fans operating in series.

Figure 1: Illustration of the experimental setup of the packed bed pilot reactor used in sanitary sewage treatment. Source: Adapted from POLAK, 2018.

The reactor operation, excluding stops caused by normal reactor pilot-scale operation adversities (such as power grid oscillations, and flow fluctuations in the ETE causing safety stops in hydraulic pumps, among others), lasted for 192 days. The operational strategies were divided into 6 stages and are summarized in Table 1.

The physical-chemical analyses for monitoring the experiment included measurements of ammoniacal nitrogen, nitrite, nitrate, and chemical oxygen demand (COD). All analyses followed the methodology outlined by the American Public Health Association (APHA) in 2005.

The behavior of the biomass attached to the Biobob® is examined by analyzing scanning electron microscopy images obtained through field emission (FEG) using the Mira 3 model from the Tescan brand.

Table 1: Experimental stages used in the present experiment.

Stages	Feed type	Aeration condition	HRT	Influent	Duration (days)
1 (start-up)	Batch	Continuous	30 days	100% IU	30
2	Continuous	15 minutes AER/15 minutes without	20 h	50% RS + 50% IU	15
3	Continuous	15 minutes AER/15 minutes without	10 h	50% RS + 50% IU	35
4	Continuous	15 minutes AER/15 minutes without	12 h	100% IU	39
5	Continuous	Without aeration	12 h	100% IU	46
6	Continuous	45 minutes AER/15 minutes without	12 h	100% IU	27

*RS: Raw Sewage. IU: UASB Influent. AER: With aeration. Without: Without aeration.

3 RESULTS AND DISCUSSIONS

Table 2 presents the characterization of the effluent used in the pilot reactor feed.

Table 2: The characterization of the influent used in the reactor feed.

Sample	TKN*	COD	TS	VS	FS	TSS	VSS	FSS
Raw Influent	45,9±19	269,7±66	195±70	32±25	163±43	121,6±30	0,010±0,01	121,000±30
UASB Effluent	35,1±12	156,9±91	208±25	90±56	118±82	11,4±15	0,002±0,03	11,380±15

*There is no significant difference between the values of TKN and NH_4^+-N

Figure 2 depicts the temporal performance of the reactor in terms of efficiencies in the stages of nitrification, denitrification, and COD removal.

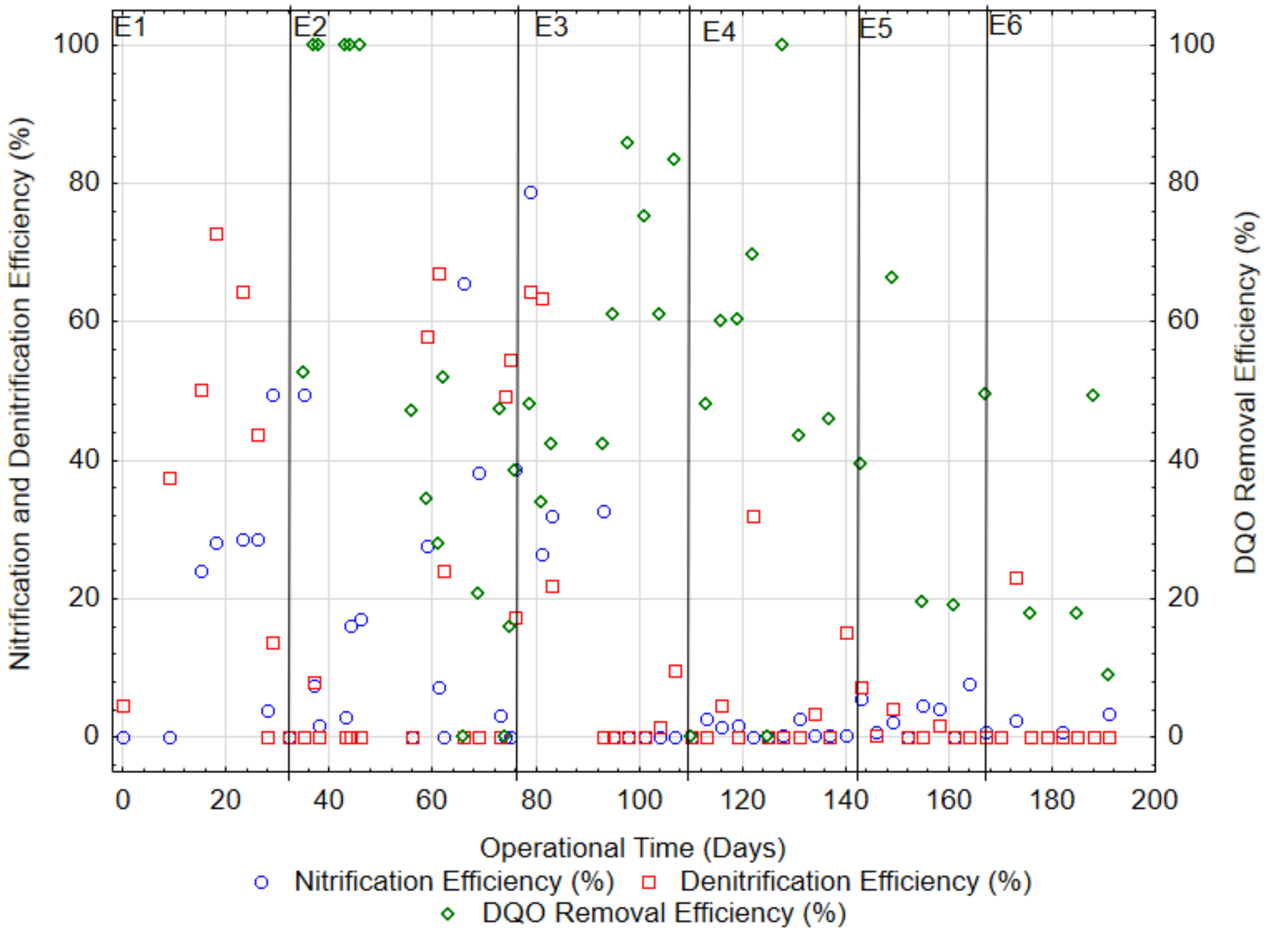


Figure 2: Simultaneous Nitrification and Denitrification Behavior and COD Removal Efficiency during the Experiment. Source: Authors work, 2023.

The nitrogen removal, especially the nitrification stage, poses greater challenges for stabilization when compared to COD removal. For this reason, starting the reactors with all three stages simultaneously (nitrification/denitrification/COD removal) uses nitrate accumulation as a starting parameter, demonstrating that nitrification is occurring in the system (BARANA et al, 2013). Within a period of 30 days, the reactor had already converted 55% of the ammoniacal nitrogen in the influent into nitrate, which signifies nitrification. This parameter allowed for the evolution of experimental conditions, including a reduction in HRT and the initiation of intermittent aeration.

Stage 2 supports the earlier observation that methanogenic archaea, along with heterotrophic bacteria that consume organic carbon, are more effective in their bioprocesses compared to nitrifying microorganisms, even when exposed to oxygen for 30 days. Once intermittent aeration began, COD removal reached rates exceeding 80% by the end of this stage. At the end of Stage 2, the reactor experienced a 72-day shutdown (caused by instabilities in the electrical grid that led to equipment damage and subsequent replacement). Consequently, Stage 3 required a fresh evaluation of nitrate accumulation. As in Stage 1, the reactor demonstrated resilience in the nitrification process. Within the first 10 days of Stage 3, nitrate accumulation was already observed with an efficiency of 40%.

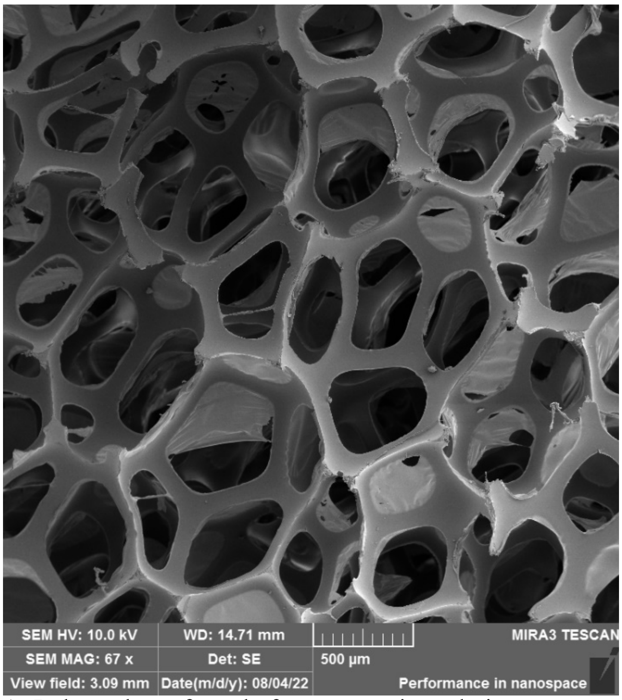
Although the reactor startup was rapid in Stage 3, even when the process was carried out with intermittent aeration, the NDS system was not stable. This necessitated an extension of the HRT from 10 to 12 hours in Stage 4. Due to mechanical issues in the ETE, the reactor was subsequently fed only with effluent from the UASB reactor. These changes resulted in only one peak of NDS nitrogen removal, which reached 35%. However, COD removal remained above 40%, with the maximum COD removal in the phase reaching 100%.

Large-scale operating systems, including pilot-scale systems, are susceptible to the everyday operational issues of a treatment plant. Therefore, Phase 5 of the experiment, due to electrical power fluctuations that affected the blower operation capacity, was conducted in anaerobic conditions, rendering the removal of nitrogen via NDS unfeasible. However, COD removal, although with lower efficiency, proceeded as usual.

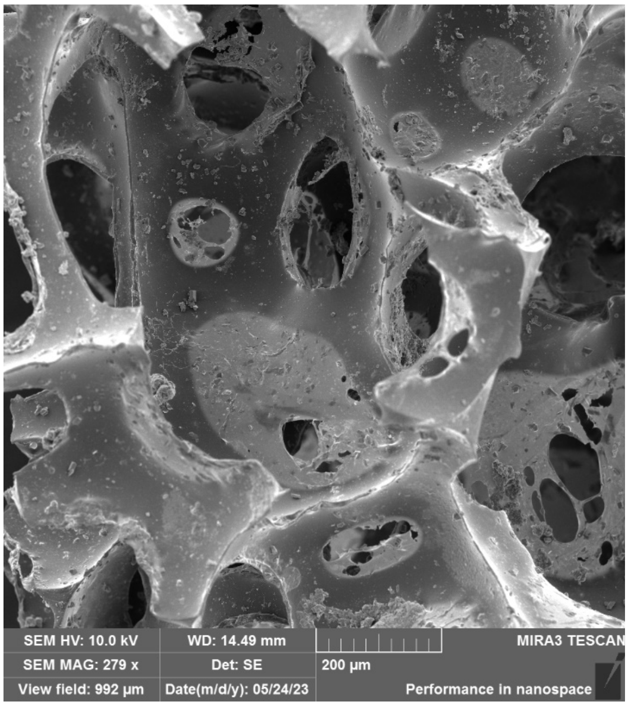
In Stage 6, the experimental conditions were restarted. However, the short operating time did not allow for significant removal rates of nitrogen and COD. Nevertheless, this stage demonstrated that the biomass attached to the Biobob® structure was still active, showcasing the resilience of the system.

It is important to emphasize that the wastewater treatment plant where the pilot reactor was installed has a discharge permit for COD set at 225 mg.L^{-1}, granted by the Water and Land Institute of Paraná, through Ordinance 1045/2020. Therefore, even with low efficiencies, the pilotreact or proved to be effective in compliance with current environmental legislation.

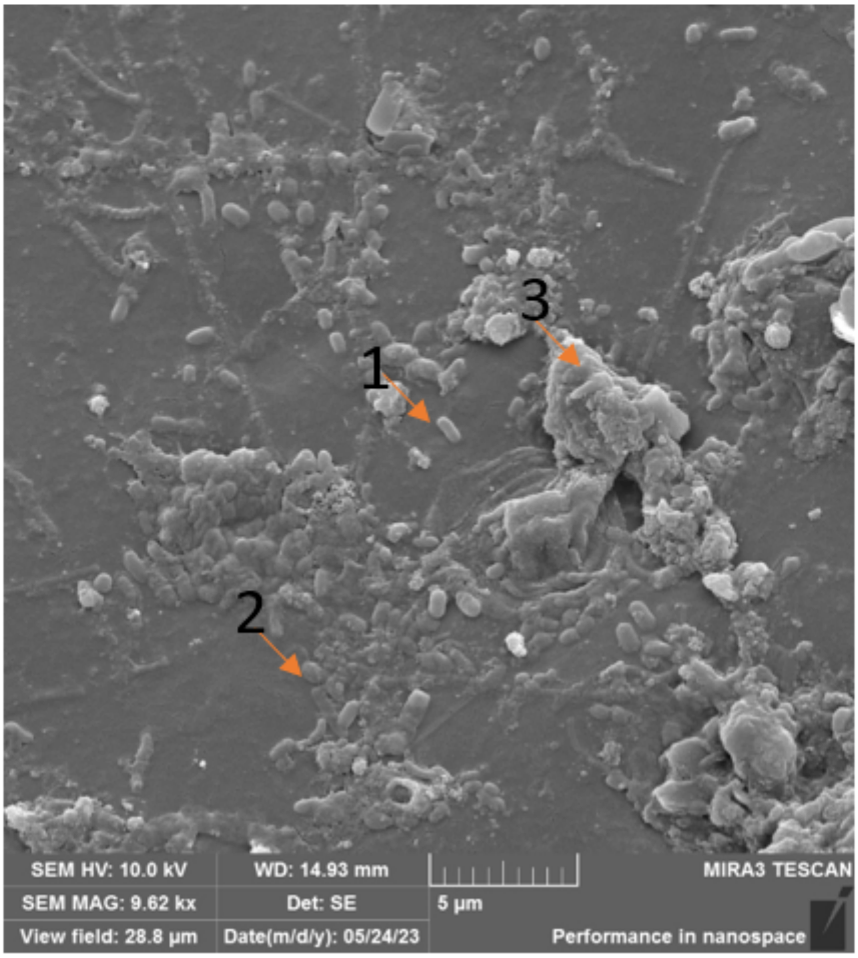
The images in Figure 3, obtained through scanning electron microscopy, depict the structure of the Biobob without biomass before the reactor inoculation (A), and at the end of the experiment (B) and (C).



A. Polyurethane foam before reactor inoculation.



B. Polyurethane foam at the end of the experiment.



C. Morphology of bacteria attached to the Biobob®, image obtained at the end of the experiment. **1**: Short Rods; **2**: Cocci; **3**: Filamentous Bacteria (Methanogenic Archaea)

Figure 3: Images of the support medium at the end of the experiment obtained by scanning electron microscopy (SEM). Source: Authors work, 2023.

Based on image A, the average diameter and average dimension of the walls between the pores were calculated. The pores of the Biobob® without biomass had an average diameter of 376.07 µm, while the spaces between the pores had an average dimension of 79.65 µm. In the image (B), it can be observed that bacteria are attached to the polyurethane structures between the pores. Since the bacteria have approximate dimensions of 5 µm (image C), the structure fulfilled its role in biomass attachment. Together with intermittent aeration, it was crucial in maintaining the anaerobic environment of the reactor, which influenced the resilience observed.

The cellular structures observed in image C are consistent with cocci and short, elongated bacilli, which are the same morphological structures identified by Azevedo et al. (2021) and Oliveira et al. (2011) when analyzing nitrifying and denitrifying sludge. Additionally, the presence of filamentous bacteria, which is the typical morphological structure of methanogenic archaea according to Oliveira et al. (2009), can be observed in the image. The observations of the cited authors reinforce that the Biobob was able to provide an anaerobic environment, ideal for both the NDS pathway of nitrogen removal and COD removal to occur simultaneously.

4 CONCLUSIONS

The most important conclusions include the reactor's efficiency in meeting the COD discharge standards for the wastewater treatment plant where it is located. The nitrogen removal process through the NDS system was achieved in the reactor, and the synergy between nitrifying and denitrifying bacteria was observed in the support medium used in the reactor.

The packed bed reactor, using Biobob® as a support medium, proved to be resilient in the usual adversities that can occur at the pilot scale, demonstrating its feasibility for use.

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6 REFERENCES

APHA, AWWA e WEF – AMERICAN PUBLIC HEALTH ASSOCIATION; AMERICAN WATER WORKS ASSOCIATION; WATER ENVIRONMENT FEDERATION (2017). Standard methods: for the examination of water and wastewater. 23.ed. Washington: American Public Health Association.

AZEVEDO, C.S. et al. (2022). Aeration and non-aeration cycles (AE/NA) time: influence in combined organic matter and nitrogen removal and features of biofilm. *Environmental Technology*, 43:16, 2443-2456. https://doi.org/10.1080/09593330.2021.1882583

BARANA, A. C. et al. (2013) Nitrogen and organic matter removal in an intermittently aerated fixed-bed reactor for post-treatment of anaerobic effluent from a slaughterhouse wastewater treatment plant. J. Environ. Chem. Eng., v.1, p.453-457. https://doi.org/10.1016/j.jece.2013.06.015

BRASIL (2020). Lei nº 14026/2020. Atualiza o marco legal do saneamento básico.

CONAMA (2005) Conselho Nacional do Meio Ambiente. Resolução no 357, de 17 de março de 2005. Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as condições e padrões de lançamento de efluentes, e dá outras providências.

CONAMA (2011) Conselho Nacional do Meio Ambiente. Resolução nº 430, de 13 de maio de 2011. Dispõe sobre as condições e padrões de lançamento de efluentes, complementa e altera a Resolução no 357, de 17 de março de 2005, do Conselho Nacional do Meio Ambiente (CONAMA).

LOPES, C. L. et al. (2022) Nitrogen removal from poultry slaughterhouse wastewater in anaerobic-anoxic-aerobic combined reactor: Integrated effect of recirculation rate and hydraulic retention time. J. Environ. Manag., v.303, p.114162. https://doi.org/10.1016/j.jenvman.2021.114162

OLIVEIRA, A. C. G. et al. (2013). NMP de bactérias nitrificantes e desnitrificantes e sua relação com os parâmetros físico-químicos em lodo ativado para remoção biológica de nitrogênio de lixiviado de aterro sanitário. Revista DAE. n. 192, p. 60-70. https://doi.org/10.4322/dae.2014.107

OLIVEIRA, J.G. B. (2020) Pós-tratamento de efluente de UASB em reator de leito empacotado com aeração intermitente em escala piloto [Tese de Doutorado em Ciência e Tecnologia em Alimentos), Universidade Estadual de Ponta Grossa, Ponta Grossa]. https://tede2.uepg.br/jspui/handle/prefix/3361

Paraná. Portaria n° 1045/2020. Dispõe sobre as condições e padrões de lançamento de efluentes da ETE Iapó. INSTITUTO ÁGUA E TERRA – IAT.

PEREIRA, E. L. et al. (2009). Efeitos do pH, acidez e alcalinidade na microbiota de um reator anaeróbio de manta de lodo (UASB) tratando efluentes de suinocultura. Ambi-Água, Taubaté, v. 4, n. 3, p. 157-168.

POLAK, R. (2018) *Reator de leito empacotado em escala piloto para remoção de matéria orgânica e nitrogenada de esgoto sanitário* [Dissertação de Mestrado em Engenharia Sanitária e Ambiental), Universidade Estadual de Ponta Grossa, Ponta Grossa]. https://tede2.uepg.br/jspui/handle/prefix/2708

STOLLE, E. M. (2022) *Remoção de nitratos de água de drenagem agrícola utilizando biorreatores com diferentes fontes de matéria orgânica* [Dissertação de Mestrado em Ciência e Tecnologia de Alimentos, Universidade Estadual de Ponta Grossa, Ponta Grossa]. https://tede2.uepg.br/jspui/handle/prefix/3759

TORRES, D. M. et al. (2019a). Estudo de caso sobre a qualidade da água do Rio Potengi na cidade de São Paulo do Potengi, Rio Grande Do Norte, Brasil. HOLOS, Ano 35, v.8, e9193. https://doi.org/10.15628/holos.2019.9193

TORRES, D. M. et al. (2019b). Tratamento de efluentes e produção de água de reuso para fins agrícolas. HOLOS, Ano 35, v.8, e9192. https://doi.org/10.15628/holos.2019.9192

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