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Use of anaerobic filters filled with waste from the ceramics industry in swine wastewater treatment

Filtros anaeróbios de resíduos de indústrias de cerâmica no tratamento de águas residuárias de suinocultura

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ABSTRACT - Research on the use of anaerobic filters as an alternative material to gravel is fundamental, especially if they are low cost and highly efficient in the treatment of swine wastewater (SWW). This study aimed to evaluate the efficiency of anaerobic filters filled with waste from the ceramic industry (WCI) as an alternative material to gravel in swine wastewater treatment. The experimental set-up consisted of three anaerobic polyvinyl chloride filters filled with WCI. A randomized block experimental design was used, with four treatments (evaluations of effects at 30, 60, 90, and 120 days) and three blocks, in a scheme of repeated measures over time. The univariate procedure was employed, and we sought to evaluate only the profile of the change in each response variable, between each evaluation time point. The anaerobic filter filled with WCI is a promising option in the treatment of swine effluents from small farms, presenting over 120 days of operation and average removals of 20%–50% of the color, 40%–70% of total solids, 45%–75% of turbidity, 45%–55% of total nitrogen, and 33%–45% of total phosphorus.

Keywords: Efficiency. Chamot. Anaerobic treatment.

RESUMO - Pesquisas utilizando filtros anaeróbios com materiais alternativos à brita tornam-se fundamentais, principalmente se forem de baixo custo e possibilitem elevada eficiência no tratamento de águas residuárias de suinocultura (ARS). Neste estudo, objetivou-se avaliar a eficiência de filtros anaeróbios preenchidos com resíduos de indústrias de cerâmica (RICs) como materiais alternativos à brita, no tratamento A bancada experimental foi constituída de 3 filtros anaeróbios de policloreto de vinila (PVC), preenchidos com RICs. O delineamento experimental utilizado foi o de blocos casualizados, com quatro tratamentos (avaliações dos efeitos aos 30, 60, 90 e 120 dias) e três blocos, em esquema de medidas repetidas no tempo, sendo adotado o procedimento univariado, buscando-se avaliar apenas o perfil das diferenças de cada uma das variáveis-resposta, entre cada uma das idades de avaliação. O filtro anaeróbio preenchido com resíduo de cerâmica apresenta-se como uma opção promissora no tratamento de efluentes de suinocultura de pequenas propriedades familiares, apresentando, ao longo de 120 dias de funcionamento, remoções médias de 20 a 50 % da cor, 40 a 70% de sólidos totais, 45 a 75% de turbidez, 45 a 55% de N-total e 33 a 45% de P-total.

Palavras-chave: Eficiência. Chamote. Tratamento anaeróbio.

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INTRODUCTION

Pig farming is of great importance to the social and economic development of Brazil, generating employment and income for producers, especially those with small farms. However, this activity could lead to serious environmental problems if the waste generated is not properly treated (LIMA et al., 2019; NAGARAJAN et al., 2019; VARMA et al., 2021).

Swine wastewater (SWW), when released without treatment into water bodies, has several environmental consequences, such as damage to water quality (BOLDS et al., 2021), fauna (CHENG et al., 2020), and flora (PROVOLO et al., 2018). Due to the high amount of nitrogen and phosphorus it contains, swine manure can cause problems of eutrophication of surface waters, resulting in loss of biodiversity, water contamination, and waterborne diseases (SEGANFREDO, 2007; AMORIM et al., 2015). In addition to surface and groundwater pollution, inappropriate application of these wastes to soil can lead to salinization, pollution, and structural damage (MATOS; MAGALHÃES; SARMENTO, 2010).

As Brazilian environmental legislation has established standards for effluent discharge into water bodies, these wastewaters require treatment. Thus, wastewater treatment becomes essential before being released into water bodies (YOTOVA et al., 2019). There are many ways to treat SWW, including duckweeds (ZHOU et al., 2019), microalgal culturing (LI et al., 2020, 2022), bacteria culturing (WEN et al., 2016), and phytoremediation (HU et al., 2020;

ZHOU et al., 2019).

Among the simple solutions proposed for the treatment of wastewater rich in organic material, as in the case of wastewater from pig farms, the anaerobic upstream filter stands out. According to Tonetti et al. (2011), anaerobic filters are a low-cost option in terms of both construction and operation, removing approximately 70% of organic matter and producing a reduced amount of sludge. These aspects make anaerobic filters ideal for application in regions lacking basic sanitation, such as small family farms in Espírito Santo state, Brazil.

One of the obstacles to the full-scale adoption of anaerobic filters refers to the cost of the filling material as a support medium, and the same value as the construction of the filter can be compared (TONETTI, et al., 2011). The same authors point out that in the sanitation of small towns, materials must be used that are widely available in their surroundings. The constant improvement of the construction process and the search for alternative more efficient, accessible, and low-cost filling materials are aspects that deserve attention for the technological development of anaerobic filters.

In this sense, research has been carried out using waste from other production processes as support media for anaerobic filters, such as construction tailings (CAMPOS; PETTER; KAUTZMANN, 2008; BAETTKER et al., 2018), bamboo rings (OZA et al., 2019; TONETTI et al., 2011), blast furnace slag (FIA et al., 2010), vegetable loofah (FERNANDES et al., 2015), tire pieces (BAETTKER et al., 2018), and coconut shells (TONON et al., 2015), among others. Among the waste generated in high quantities in the state of Espírito Santo, waste from the ceramic industry (WCI) stands out. These residues are composed of pieces that contain some defects, such as cracks, when they leave the process broken or burned to the point of fragility and do not pass quality control; such pieces are commonly referred to as "chamot". Most of the time, these residues are discarded in inappropriate places, impacting on the landscape in several locations in Espírito Santo State.

To take advantage of these residues, we put forward the hypothesis that WCI is a promising alternative to replace the use of gravel as a support material in anaerobic filters in the treatment of swine wastewater. In addition to providing a practical and environmentally appropriate destination for this waste, its use will reduce the costs of managing this waste in the municipality and extend the useful life of landfills.

Therefore, this study aimed to evaluate the efficiency of anaerobic filters filled with WCI as an alternative material to gravel in the treatment of swine wastewater.

MATERIAL AND METHODS

The experiment was implemented and conducted at the pig farm of the Federal Institute of Espírito Santo (IFES) *Campus* Santa Teresa, municipality of Santa Teresa, Espírito Santo state (19º48′21″S, 40º40′44″W). The altitude is 150 m, and the region is characterized by a tropical climate, with average annual temperature and rainfall of 28 °C and 1,078 mm, respectively, classified as Aw (ALVARES et al., 2013).

The experimental stage was carried out between December 2020 and March 2021, obtaining average temperatures of 26.7, 26.3, 25.6, and 24.6 °C, in the months of December, January, February, and March, respectively.

The swine wastewater used in the tests was collected in a reservoir on the IFES Experimental Pig Farm – *Campus* Santa Teresa, in Santa Teresa, ES, Brazil.

The experimental set-up consisted of three anaerobic polyvinyl chloride filters, 100 mm in diameter and 0.80 m high, with a capacity of 6.28 L each (Figure 1).

Figure 1. Filters used in the experiment.

As the filling material for the filters, WCI, also known as “chamotte”, was used, with a void volume of 0.365 L L^{-1}, acquired from a ceramic factory in the Municipality of São Roque do Canaã, ES. This waste is classified by the ABNT NBR 10004/2004 standard class II B as inert and non-hazardous. The WCI was washed, sun-dried, crushed in a hammer mill, and sieved to obtain a granulometric range between 3 and 5 mm. After sieving, the WIC was placed in the filters up to a height of 0.65 m, as shown in Figure 2.

The filters were fed by an upward flow of wastewater from the pig farm in the large animal department on the IFES campus. The effluent was deposited in a water tank with a capacity of 1,000 L, installed in a structure 1.5 m above the filters, causing them to be fed by gravity (Figure 3).

Figure 2. Filters filled with waste from the ceramic industry.

Figure 3. Experimental set-up.

The effluent retention time in the filters was 3.3 h in the first 60 days and 4 h in the remaining 60 days, corresponding to flow rates of 0.57 and 0.47 L h^{-1} and application rates of 1,742.4 and 1,436.9 L m^{-2} d^{-1}, respectively. The raw effluent was monitored and treated for a period of 4 months, and a total of four samples were removed every 30 days.

Analysis of the raw and treated effluent consisted of pH, turbidity, color, total nitrogen (N-total) and total phosphorus (P-total) determinations. The analyses were performed at the IFES Water Quality Laboratory – Santa Teresa *Campus*, following the methodology described by Matos (2015).

The evaluated variables and the methods and devices used in the laboratory analyses are described in Table 1.

Table 2 shows the characteristics of the raw effluent (swine wastewater) from the four sampling sessions during the experimental stage.

Table 1. Evaluated variables and the respective methods used for analysis.

Variables	Method/Device
Turbidity	Benchtop turbidity meter
Color	Colorimeter
Total Solids (TS)	Gravimetric
Total Nitrogen (N_{Total})	Semi-micro Kjeldahl
Total Phosphorus (P_{Total})	Spectrophotometry

Table 2. Characteristics of raw wastewater during the experimental stage.

Time (days)	pH	Color	Turbidity	N-total	P-total
		uHz	UNT	------------------mg L^{-1}------------------	
30	7.20	341	75.3	-	-
60	7.30	417	75.3	252.0	26.24
90	6.95	361	124	238.0	44.53
120	7.15	880	509	210.0	38.74

To determine the removal efficiency of the filters (E), the values of the concentrations of the affluent and effluent of the filters, calculated using Equation 1, were considered.

$$E(\%) = \frac{(C_{af} - C_{ef})}{C_{af}} \times 100 \qquad (1)$$

,

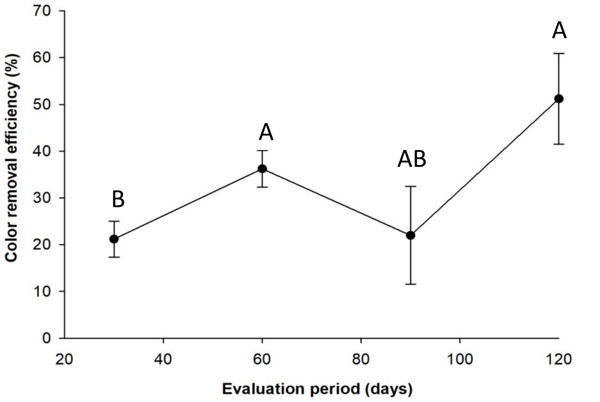
Where:
C_{af}: affluent concentration;
C_{ef}: effluent concentration;
E: removal efficiency, %.

A randomized block experimental design was used, with four treatments (evaluations of the effects at 30, 60, 90, and 120 days) and three blocks, in a scheme of repeated measurements over time. The univariate procedure was employed, and we sought to evaluate only the profile of the change in each response variable between each evaluation time point (intra-subject). Prior to statistical analysis, the studied variables were submitted to the Shapiro-Wilk test for normality and Levene’s test for homoscedasticity, in addition to the Mauchly test. The purpose of the latter was to verify the condition of sphericity or to meet the conditions of similarity of variances and null correlations of a normal multivariate population. In the case of non-compliance with the sphericity condition, the degrees of freedom were corrected using the methods of Greenhouse-Geisser and Huynh-Feldt (STEEL; TORRIE; DICKEY, 1997). In the case of a significant effect ($P < 0.05$), for comparisons of variables at different time points, the t-test with a Sidak correction was also used to show the confidence intervals for the means, with 95% confidence. The R program (R DEVELOPMENT CORE TEAM, 2019) was used to perform the analyses.

RESULTS AND DISCUSSION

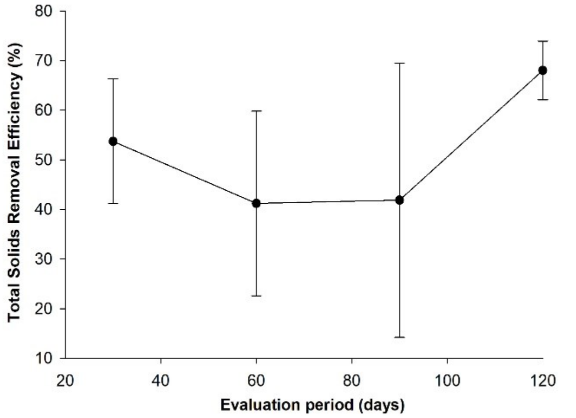
Figure 4 shows the average data for color removal efficiency (4A), Total Solids (4B), Turbidity (4C), Total Nitrogen (4D) and Total Phosphorus (4E), in anaerobic filters filled with ceramic waste, in the treatment of swine wastewater, over 120 days of monitoring.

(A)



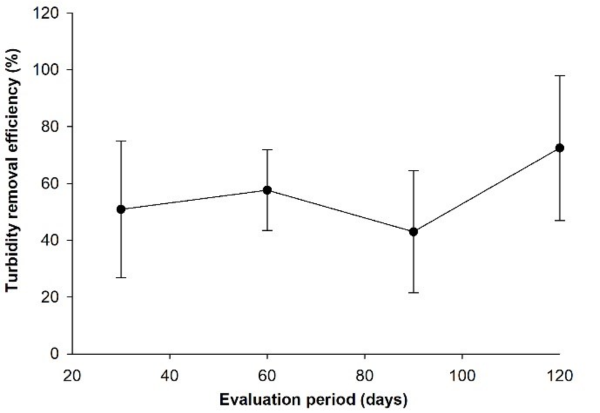
Increasing linear effect: P = 0.005. Comparisons made based on the confidence intervals (CI) of the average with 95% Confidence: Averages followed by the same letters are equal to each other by the Sidak test. α= 5%.

(B)



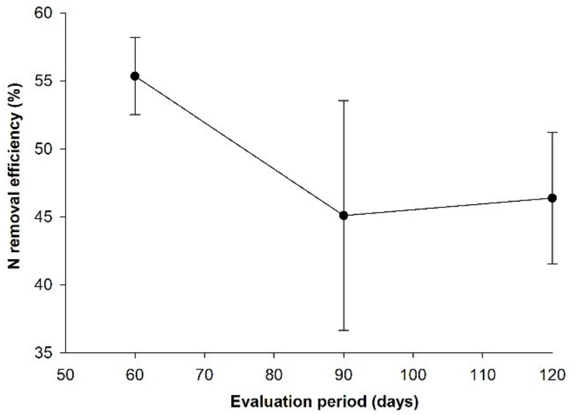
Absence of differences between the means: 95% CI and Sidak test.

(C)



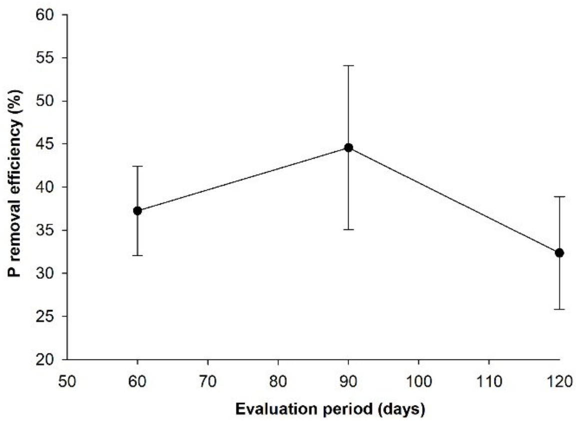
Cubic Effect: 0.015. Absence of differences between the means: 95% CI and Sidak test.

(D)



Linear Effect: 0.037. Absence of differences between the means: 95% CI and Sidak test.

(E)



Linear Effect: 0.013. Absence of differences between the means: 95% CI and Sidak test.

Figure 4. Average data for removal efficiency of Color (A), Total Solids (B), Turbidity (C), Total Nitrogen (D), and Total Phosphorus (E), in anaerobic filters filled with ceramic waste, in the treatment of wastewater from pig farming, over 120 days of monitoring.

There were no statistically significant differences between the evaluative means for the response variables, except for the color variable (Figure 4A), in which there was a significant difference between the removal efficiency that occurred at 30 days and at other time points. At 90 days of monitoring, however, there was no difference regarding the removal efficiency obtained at 30 days. It was expected that with the time of operation of the filters, the removal efficiency would increase, a phenomenon that occurred at 60 and 120 days, but not at 90 days. In the period close to the analyses performed at 90 days, it was observed that the filters started to clog, as evidenced by a decrease in the flow rate through the filters. In this sense, it is possible that the post-clogging maintenance may have contributed to the dragging and transportation of the lower-density sludge trapped in the interstices of the support material for the wastewater being treated (post-filter), providing higher values in the treated effluent and, consequently, corroborating the lowest values of removal efficiency.

Color is associated with the presence of dissolved solids (VON SPERLING, 2005; FERREIRA et al., 2022) and, although it is not necessarily related to problems of contamination of water bodies, it causes problems of an aesthetic nature and hinders light penetration. In addition, it may be related to recalcitrant compounds that, in this case, in general, are toxic to the aquatic community (PIVELI; KATO, 2005; BENDER; SOUZA; VIDAL, 2019). In any case, removal of 20%–50% of the color was obtained by use of filters filled with WCI during the 4 months of monitoring. These results can be considered satisfactory, since there was no preliminary or primary treatment before the waste was passed through the anaerobic filter.

Higher color removal values were found in research with other types of treatment: up to 92% removal using SWW electrolysis (CHO; LEE; RA, 2010), up to 98,9% removal combining biological treatment, struvite crystallization, and electrochemical treatment (SHIM et al., 2020), up to 97,8% removal using anaerobically digested swine wastewater using an intermittent cycle extended aeration system (DAN; RENE; LE LUU, 2020).

Regarding the variable Total Solids (Figure 4B), although there was no significant difference between time points, an efficiency of removal of 40% was observed initially, and a value close to 70% was reached at the end of 120 days of monitoring. This result can also be deemed satisfactory, considering that in the corresponding period of operation (at the end of 120 days), Oza et al. (2019) obtained values lower than those in the present study, reaching removal levels of 47.5% of total solids in anaerobic filters filled with gravel; 52.36% in filters filled with bamboo rings; 42.82% in filters filled with cuttings of vegetable loofah, and 49.45% in filters filled with polyurethane foam. It is noteworthy that the authors obtained these results using a 12-hour hydraulic remaining time (HRT), which was higher than the value used in this study (4-hour HRT, from 60 to 120 days).

The removal of turbidity from wastewater is of paramount importance, since this water quality parameter is related to the presence of suspended solids (VON SPERLING, 2005). If the effluent is released without treatment in water bodies, the presence of suspended solids can reduce the penetration of light and impair photosynthesis by algae and, consequently, the production of oxygen in the water body (NANDORF et al., 2021). Thus, it appears that the anaerobic filter filled with ceramic waste removed turbidity and total solids with similar efficiency (Figure 4C), between 45% and 75%.

Higher values (91% and 97.4%) were found by Mores et al. (2016) and Emerick et al. (2020), respectively, with electrocoagulation treatment, and 75% by Chhetri et al. (2022) using magnetic nanosponges.

If the effluent is to be released into water bodies, the removal of N-total and P-total from swine wastewater becomes essential, since they are the elements that contribute the most to the eutrophication process, impacting on the environment in several ways (NANDORF et al., 2021). According to Figure 4D, nitrogen removal ranged between 45% and 55% over 120 days of monitoring. The high removal, mainly after 60 days of operation (January), may be related to the evolution of the biofilm, the higher biochemical activity due to the high temperatures in this period, and the incorporation of nitrogen into the biomass itself.

The efficiency of N-total removal obtained in this study was superior to that obtained by Tonetti, Coraucci Filho, and Stefanutti (2012), who, when evaluating the post-treatment of anaerobic filter effluents with bamboo filling, found an efficiency of only 16%, with HRT of 3 h, similar to that in the present study (3.3–4 h). The results obtained in this study were also superior to those of Silva and Campos (2018), which achieved removal of 33.1%, using Pall rings as a support medium, confined in plastic meshes, in the treatment of swine effluent, with a 94-hour HRT, 7 hours in the first phase (55 days) and a 63.1-hour HRT in the second phase (87 days). It is believed that if the HRT used in this experiment were higher, the filters filled with ceramic residues would provide a greater removal efficiency, since there would be a longer contact time of nutrients with the biofilm and possibly greater incorporation of nitrogen into the biomass itself.

Regarding the total phosphorus variable (Figure 4E), removals of 33%–45% were obtained over the 120 days of monitoring. Such results can be considered satisfactory since phosphorus and nitrogen are not efficiently retained in anaerobic filters. According to Chernicharo (2007), anaerobic filters have a disadvantage with respect to the low efficiency of removal of N and P, requiring the application of a post-treatment.

CONCLUSION

We evaluated the efficiency of anaerobic upstream filter filled with ceramic residue, and it presents itself as a promising option in the treatment of swine effluents from small farms, presenting, over 120 days of operation and average removals of 20%–50% of the color, 40%–70% of total solids, 45%–75% of turbidity, 45%–55% of N-total, and 33%–45% P-total. The filters can be considered an efficient option for SWW due to it's low-cost of construction and simple to operate, but more studies can be carried out to evaluate its performance when used after primary or preliminary treatments.

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