Revista Ciência Agronômica, v. 52, n. 2, e20196937, 2021
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Scientific Article
ISSN 1806-6690

Performance of a hybrid anaerobic reactor in the treatment of swine wastewater[1]

Desempenho de reator anaeróbio híbrido no tratamento de águas residuárias de suinocultura

Gustavo de Castro Gonçalves[2], Alisson Carraro Borges[2*], Nilton de Freitas Souza Ramos[2], Tamara Daiane de Souza[3], Antonio Teixeira de Matos[4] and Cecília de Fátima Souza[2]

ABSTRACT - The aim of this study was to evaluate the performance of a hybrid anaerobic reactor (HAR) in treating swine wastewater (SWW). The reactor was operated under different volumetric organic loading rates (based on working volume), of 0.85, 1.35 and 2.62 kg m^{-3} day^{-1} COD. The operation lasted 250 days, with a mean removal efficiency based on the filtered COD of 67%, 81% and 82% respectively for the three applied organic loading rates (OLR). At the end of the experiment, the COD removal profile was evaluated throughout the reactor to obtain the decay coefficients (k), where the first-order model best fit the data. The value for k was estimated at 0.041 h^{-1} and 0.077 h^{-1} for a OLR of 1.35 and 2.62 kg m^{-3} day^{-1} respectively. The reactor proved to be a good alternative for the anaerobic treatment of swine wastewater. The increase in OLR did not affect the ability of the reactor to remove organic material.

Key words: Anaerobic digestion. Polyurethane foam. Agro-industrial effluent. Livestock.

RESUMO - Objetivou-se com a realização deste estudo avaliar o desempenho de um reator anaeróbio híbrido (RAH) no tratamento de águas residuárias da suinocultura (ARS). O reator foi operado com diferentes cargas orgânicas volumétricas (CV_u) de 0,85; 1,35 e 2,62 kg m^{-3} d^{-1} de DQO. A operação do RAH durou 250 dias e as eficiências médias de remoção, com base na DQO filtrada, foram de 67; 81 e 82%, para as três CV_u aplicadas, respectivamente. Ao final do experimento avaliou-se o perfil de remoção de DQO ao longo do reator para a obtenção dos coeficientes de degradação (k), em que o modelo de primeira ordem foi o que melhor se ajustou aos dados obtidos. Os valores de k foram estimados em 0,041 e 0,077 h^{-1} para as CV_u de 1,35 e 2,62 kg m^{-3} d^{-1}, respectivamente. Pode-se observar que o reator apresentou ser boa alternativa no tratamento anaeróbio de efluentes suinícolas. O aumento na CV_u não afetou a capacidade do reator na remoção do material orgânico presente.

Palavras-chave: Digestão anaeróbia. Espuma de poliuretano. Efluentes Agroindustriais. Pecuária.

DOI: 10.5935/1806-6690.20210017
Editor do artigo: Professor Alek Sandro Dutra - alekdutra@ufc.br
*Author for correspondence
Received for publication 27/09/2019; approved on 21/08/2020

[1] Extraído da dissertação de mestrado do primeiro autor, apresentada ao Programa de Pós-Graduação em Eng. Agrícola / Recursos Hídricos e Ambientais da UFV.

[2] Departamento de Engenharia Agrícola, Universidade Federal de Viçosa/UFV, Viçosa-MG, Brasil, gustavo.goncalves@ufv.br (ORCID ID 0000-0003-3781-9397), borges@ufv.br (ORCID ID 0000-0002-9729-6439), nilton.ramos@ufv.br (ORCID ID 0000-0002-5032-0358), cfsouza@ufv.br (ORCID ID 0000-0002-0313-1327)

[3] Departamento de Engenharia Urbana, Universidade Federal de Ouro Preto/UFOP, Ouro Preto-MG, Brasil, tamaradaianesouza@gmail.com (ORCID ID 0000-0002-6849-5877)

[4] Departamento de Eng. Sanitária e Ambiental, Universidade Federal de Minas Gerais/UFMG, Belo Horizonte-MG, Brasil, atmatos@desa.ufmg.br (ORCID ID 0000-0003-4791-8399)

INTRODUCTION

Pig farming is one of the areas that has most developed in recent years, and occupies a prominent position in Brazilian agribusiness. The adoption of so-called confined production systems contributes to the technical quality and high productivity of the sector. However, the viability of the activity may be threatened due to environmental regularisation, since swine wastewater (SWW) is considered to have a high polluting potential, especially in relation to its organic load (LIM; FOX, 2011).

The application of such techniques as ponds, dunghills, soil disposal and anaerobic digestion has been recommended in the treatment/disposal of SWW, as the demand from producers is for low-cost systems and simplified operation. Anaerobic systems are characterised by low values for sludge production, energy consumption and operating costs (CHENG *et al*., 2018).

The most-used anaerobic reactors for treating SWW are rural biodigesters and UASB (upflow anaerobic sludge blanket) reactors, considered alternatives for large and small agricultural properties. Although in Brazil the technology is well-established, some disadvantages are still attributed to anaerobic reactors, such as the bad smell, the low capacity of the system to tolerate toxic substances, the time required to start the system, the need for post-treatment of the effluent, and the risk of granules escaping with the treated effluent.

As a result, modified models have been developed with the aim of both increasing the efficiency and reducing the cost of the equipment used in the system; noteworthy among current possibilities, are anaerobic systems with hybrid configurations (MORTEZAEI; AMANI; ELYASI, 2018).

Hybrid anaerobic reactors (HAR) can be considered modified anaerobic filters, using a combination of free and fixed microorganisms in the same system. The biomass concentration of the reactor is therefore higher, with improved purification of the effluent and no significant increase in implementation costs. The HAR combines the characteristics of anaerobic fluidised bed reactors - taking advantage of higher upflow speeds - and UASB reactors - using immobilised biomass. The sludge blanket is maintained under fluidised conditions, eliminating dead zones and providing efficient contact between the effluent and biomass, with a relatively low requirement in terms of area and volume. The literature points out that the HAR gives better results in removing dissolved organic matter. Compared to other reactors, another advantage of the hybrid reactor is the ability to withstand higher organic loads (MORTEZAEI; AMANI; ELYASI, 2018; RAVICHANDRAN; BALAJI, 2019). A combination of these advantages makes the HAR promising for the treatment of industrial wastewater containing high levels of biodegradable organic material (GUPTA; SREEKRISHNAN; SHAIKH, 2018; WOLFF; PAUL; COSTA, 2010).

Despite all the registered research, there is still a need to expand investigations into the management of SWW in anaerobic systems, as well as to find new configurations aimed at improving performance, simplifying the various processes, and employing materials that are easy to obtain on the market.

Given the above, the overall aim of the present study was to evaluate the efficiency of a hybrid anaerobic reactor in treating swine wastewater under increasing loadings of organic material. It was also sought to analyse the distribution profile of solids and organic material throughout the height of the HAR during the experimental period.

MATERIAL AND METHODS

The experiment was conducted on a pig farm located in the city of Viçosa, Minas Gerais, in the southeast of Brazil. During the study, the herd included approximately 70 females, with a daily production of around 15 m^3 of swine wastewater (SWW).

The reactor was built using a high-density cylindrical polyethylene (HDPE) tank, 2.38 m in diameter and 2.43 m in height, with a total capacity of 10 m^3. Structural adaptations were made to the inside of the tank so that the upper part could accommodate the support material at a distance of 1.45 m from the bottom. The layer of support material had a total thickness of 0.70 m, occupying a total volume of approximately 3 m^3. Due to the high porosity of the material, the tank had a corresponding working volume of 2.8 m^3.

The distribution structure installed at the bottom of the reactor consisted of PVC tubing 50 mm in diameter, perforated with holes 5 mm in diameter. The holes were drilled 2 cm apart in every direction throughout the distributor.

A similar structure was built at the top of the reactor to capture the effluent; however, care was taken that the two structures were not aligned, in order to avoid the creation of short circuits and preferential pathways.

Four valves were installed along the height of the reactor to allow the SWW to be sampled and the excess sludge to be removed. The first valve was installed 0.50 m from the bottom. Figure 1 shows a schematic drawing of the proposed reactor.

The hydraulic load of the SWW inflow to the reactor was kept constant by means of a reservoir with level control. To start the system, the excess sludge from a UASB-type reactor treating sanitary sewage was used as the inoculum. The sludge had a biochemical oxygen demand (BOD) of 1255 mg dm^{-3}, a chemical oxygen demand (COD) of 5682 mg dm^{-3} and total volatile solids (TVS) of 2992 mg dm^{-3}.

Polyurethane foam, cut into cubes of 7 cm, was used as the support material for immobilising the inoculum. The support material was free of additives or dyes, had a porosity of 0.93 m^3 m^{-3} and an apparent bulk density of 23 kg m^{-3}. During the immobilisation process, 0.3 m^3 of sludge were used.

The total operating time of the hybrid anaerobic reactor was 250 days. To analyse the performance and stability of the system, the study was divided into three operational phases: I, II and III, lasting 76, 110 and 64 days respectively.

Operation of the reactor comprised a gradual increase in the influent flowrate, resulting in an increase in the applied organic load and a reduction in the hydraulic retention time.

The working volume of the reactor was considered when obtaining the operational variables during the experimental period, since this better represents the conditions to which the reactor was subjected. The operational conditions applied in the study are summarised in Table 1.

Figure 1 - Schematic drawing of the hybrid anaerobic reactor

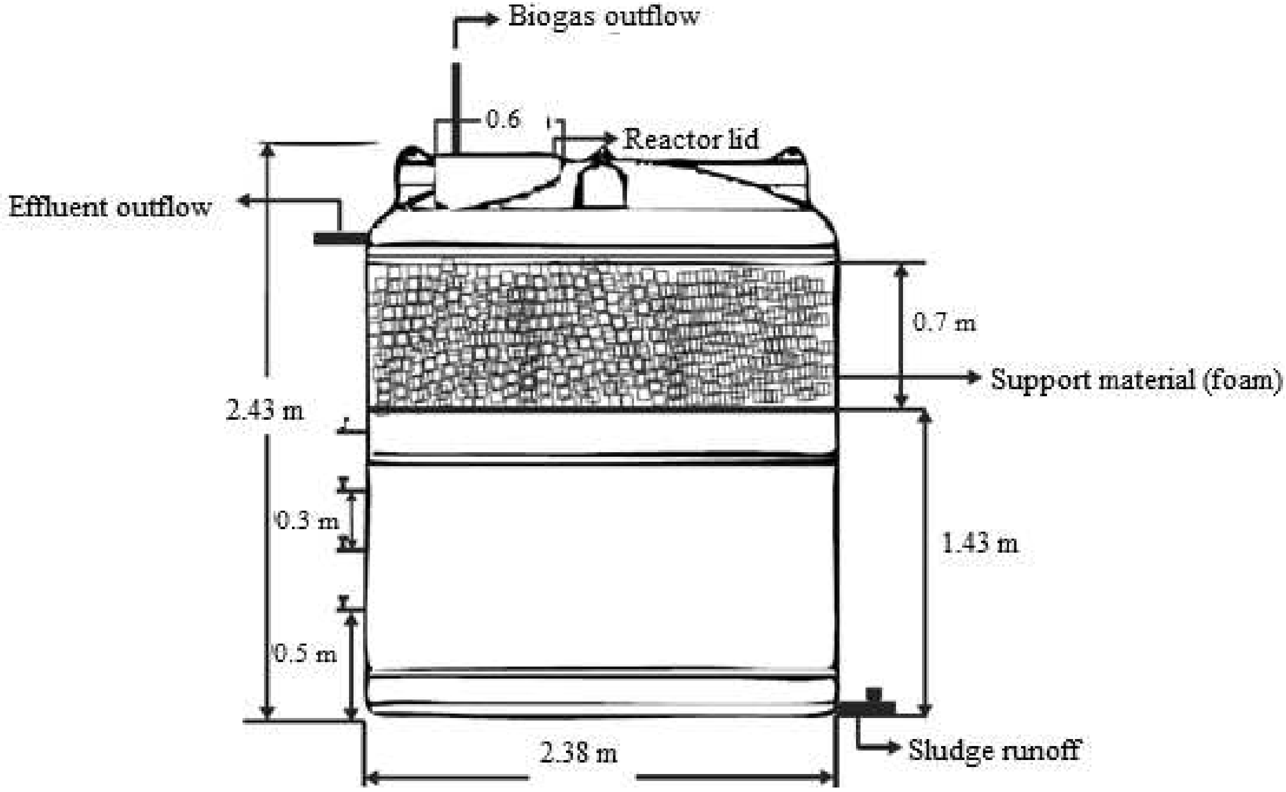


Table 1 - Operational characteristics of the hybrid anaerobic reactor

Variable	Phase		
	I	II	III
Q^1 (m^3 day^{-1})	2.6±0.9	4.6±0.6	9.0±0.2
HLR^2 (m^3 m^{-3} day^{-1})	0.3±0.09	0.5±0.08	1.0±0.05
HRT^3 (h)	91±1.3	48±0.5	24±0.06
$OLR_w{}^4$ (kg m^{-3} day^{-1} COD)	0.85±0.46	1.35±0.50	2.62±0.85
$OLR_t{}^5$(kg m^{-3} day^{-1} COD)	0.78±0.42	1.29±0.46	2.40±0.78
Duration (d)	76	110	64

^{1}Q = influent flowrate; ^{2}HL = Hydraulic loading rate; ^{3}HRT = Hydraulic retention time; $^4OLR_w$ = COD volumetric organic loading rate, considering the working volume of the reactor; $^5OLR_t$ = COD volumetric organic loading rate, considering the total volume of the reactor

The analysis was carried out as per the recommendations of the Standard Methods for the Examination of Water and Wastewater (AMERICAN PUBLIC HEALTH ASSOCIATION, 2017), for the following variables: pH, turbidity, chemical oxygen demand (COD), biochemical oxygen demand (BOD), total solids (TS), total volatile solids (TVS), volatile suspended solids (VSS) and total phosphorus (TP). The total nitrogen (TN) was quantified as per the semi-micro Kjeldahl method, with the addition of salicylic acid to determine the total nitrogen.

At the end of phases II and III, COD removal was evaluated throughout the height of the reactor together with the solids profile. The COD data were used to obtain the apparent kinetic coefficients of organic matter decay. The adjusted models were the first-order kinetic model, the first-order model with residuals, the first-order model with delay, and the first-order model for tanks in series, these models being used repeatedly in the literature on environmental engineering (DOTRO *et al*., 2017; SHEPHERD *et al*., 2001). Samples were collected at six points in the reactor, corresponding to the inlet, four points on the sludge bed, and the outlet.

The D'Agostino-Pearson test was applied to verify the homogeneity and normality of the data, using the samples in each phase as replications. The analysis of variance was then carried out using the Kruskal-Wallis test (α=0.05) whenever there was a significant effect from the factors and when the data were non-parametric. For the parametric data, ANOVA followed Tukey's test (α=0.05) was used. In all the above analyses, a completely randomised design was considered.

RESULT AND DISCUSSION

The principal physical and chemical characteristics of the SWW influent to the HAR, considering the variables under analysis (pH, turbidity, COD, BOD, TS, TVS, VSS, TP and TN) are shown in Table 2.

As can be seen in Table 2, the swine wastewater (SWW) had a mean value for chemical oxygen demand (COD) higher than that found by Lim and Fox (2011) and Lee *et al*. (2004). Araújo *et al*. (2012), report that the composition of animal waste is associated with such factors as the adopted management, type and size of the animal, functioning of the drinking fountains and the hygiene system being used. Another important factor is the temperature of the environment, since it is known that at higher temperatures water consumption by the pigs and for cleaning is greater. As such, the concentration of waste components can vary widely depending on the different situation of each pig farm.

Suitable conditions were seen in the HRA under evaluation with respect to buffering capacity. Values between 6.69 and 7.84 were found for the pH of the influent to the reactor. When monitoring the effluent from the reactor, values ranging from 6.65 to 7.33 were seen, with an average of 7.01. It is known that buffering capacity in anaerobic reactors is an important parameter for assessing correct operation, and the synergy between bacteria and methanogenic archaea (LIU *et al*., 2011). The operating cost of the reactor is considered reduced when the variation in pH is small, as found in this study, making the addition of alkalising substances unnecessary, and increasing efficiency.

Figure 2 shows the variations in organic matter concentration in terms of COD, for the influent, and the unfiltered and filtered effluent, obtained during phases I, II and III of reactor operation.

Phase I, typically characterised as a phase of instability, showed greater fluctuations in volumetric organic loading relative to COD. For an initial flowrate

Table 2 - Concentration (mean ± standard deviation) of the SWW inflow to the HAR during the experimental period

Variable	Unit	SWW
pH	-	7.19±0.34
Turbidity	(NTU)	1015.5±50.2
Chemical oxygen demand (COD)	(mg dm^{-3})	2816±1281
Biochemical oxygen demand (BOD)	(mg dm^{-3})	1095±382
Total solids (TS)	(mg dm^{-3})	4752±2696
Total volatile Solids (TVS)	(mg dm^{-3})	2694±1360
Volatile suspended solids (VSS)	(mg dm^{-3})	573±876
Total phosphorus (TP)	(mg dm^{-3})	40.9±22.2
Total nitrogen (TN)	(mg dm^{-3})	279.0±119.99

of approximately 2.6 m^3 day^{-1}, the OLR_w and HRT were 0.85 ± 0.46 kg m^{-3} day^{-1} and 3.8 ± 1.2 days respectively, and the COD removal efficiency, in total terms, was 43 ± 14%. Variations in both the influent COD and the flowrate resulted in fluctuations in OLR_w and HLR_w, which then caused instability in reactor performance during this first phase.

After 77 days of operation, it was found that the system reached steady state, with efficiency at uniform levels. During phases II and III, the mean efficiency for total (unfiltered) and filtered COD removal was 72 ± 8% and 81 ± 8% for phase II, and 73 ± 8% and 86 ± 4% for phase III respectively. The mean removal efficiency of the other monitored variables during each operational phase are shown in Table 3.

It can be inferred that the system achieved satisfactory results regarding the reduction in organic load. Given their limited efficiency and long period for the system to stabilise, UASB reactors are characterised by the need for complementary treatments. Data from the literature indicate an efficiency for UASB reactors of the order of 40% to 60%, the upper limit being reached when low organic loads are applied and environmental conditions are extremely favourable (LATIF *et al*., 2011; MOTNALVO *et al*., 2014). Therefore, the HAR under study can be considered more promising compared to the UASB reactor in relation to the efficiencies achieved and the time needed for stabilisation, which is why it is extensively addressed in the literature.

Figure 2 - Variation in COD in the unfiltered influent, and the filtered and unfiltered effluent of the hybrid anaerobic reactor

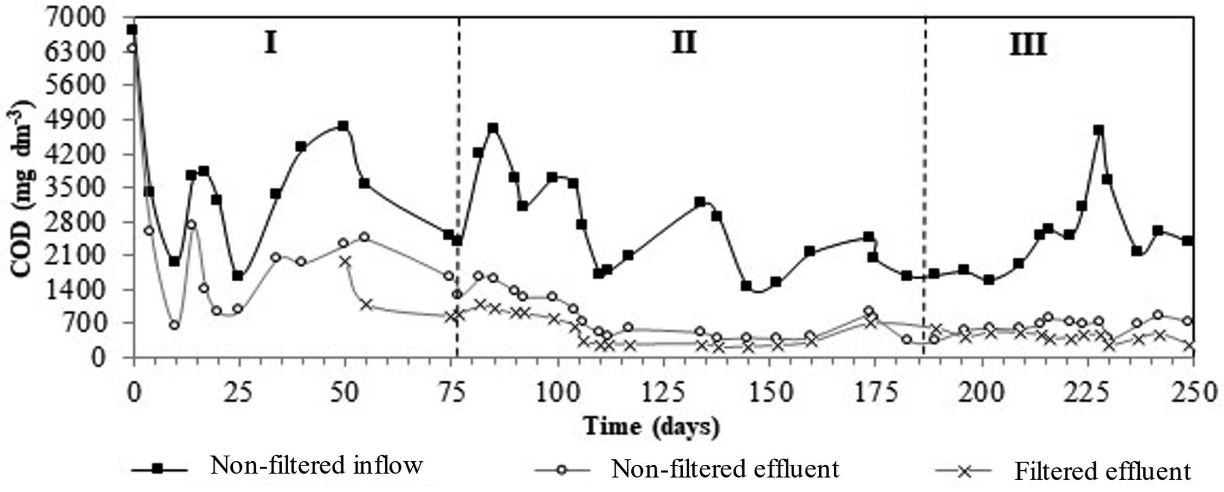


Table 3 - Removal efficiency (mean ± standard deviation) for total COD (COD$_{T)}$, filtered COD (COD$_F$), biochemical oxygen demand (BOD), total solids (TS), total fixed solids (TFS), total volatile solids (TVS), total suspended solids (TSS), fixed suspended solids (FSS), volatile suspended solids (VSS) and total dissolved solids (TDS) in the hybrid aerobic reactor during each operational phase

Variable	Phase		
	I	II	III
COD_T	43±15	72±7	73±6
COD_F	68±7	81±6	82±5
BOD	ND[1]	75±6	78±5
TS	53±15	60±16	58±8
TFS	74±8	35±37	38±22
TVS	31±7	62±17	61±9
TSS	20±27	56±21	53±17
FSS	49±14	55±26	43±14
VSS	17±13	55±6	62±13
TDS	46±22	48±16	48±10

[1] Not determined

The removal of organic material in terms of BOD, monitored during phases II and III, was 75 ± 6% and 78 ± 5%, showing significant values for the removal of biodegradable organic material, and compliance with federal legislation, as per Conama Resolution 430/2011. It is important to point out that the mean values found for BOD removal efficiency were higher compared to the values for total COD efficiency, but were no higher than the values found for filtered COD. This can be explained by part of the biomass in the reactor being carried with the effluent, thereby validating the evaluation of the filtered COD. Removal efficiency for solids in the reactor was found to be good during each operational phase, with mean values of 53 ± 15%, 60 ± 16% and 58 ± 8% for the removal of TS, and 31 ± 15%, 62 ± 17% and 61 ± 9% for the removal of TVS during phases I, II and III respectively. Even with a large variation in the concentration of TS and TVS in the inflow, the HAR showed the ability for damping solids and for their satisfactory removal.

At the end of phases II and III of reactor operation, the COD and solids profiles were determined along the height of the reactor, where valves were installed to collect the SWW.

The COD profiles obtained in the reactor during the last two phases of operation of the system showed a gradual reduction in value along the height of the reactor. Nonlinear regression analysis for both phases, using first-order kinetics, showed a strong correlation between the height of the reactor and the decreasing concentration of organic material.

The solids profile of the reactor for phases II and III shows a dense concentration of solids at the bottom of the reactor. The presence of the sludge blanket allows for the deposition of a large volume of suspended solids in the lower part of the reactor, where there is little mixture due to the formation of gas bubbles. In addition, the support material acts as a physical barrier, reducing the speed of the solid material, and allowing it to be deposited at the bottom of the system (YU; ZHAO; TANG, 2006). It should be noted that the periodic removal of excess sludge was another important factor, responsible for the efficiency of the system in the stable removal of COD and solids.

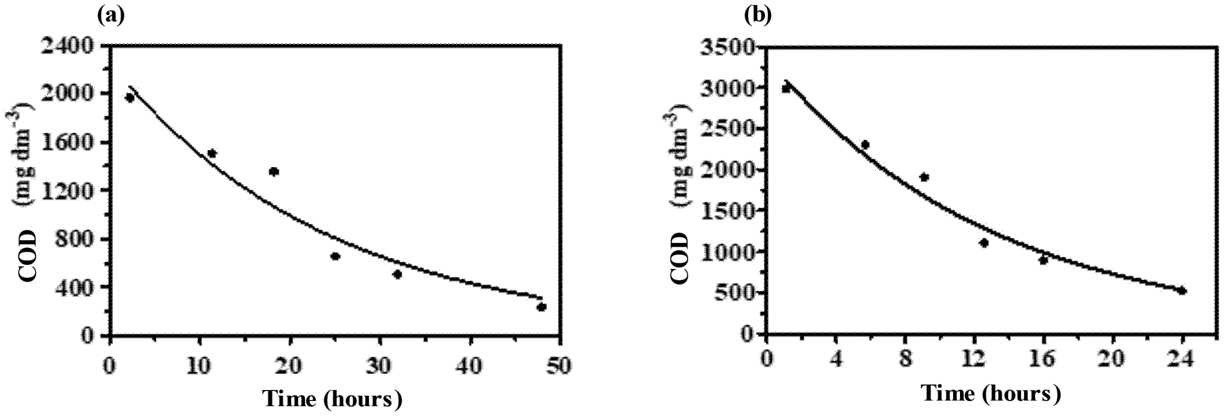
The kinetic parameters were obtained from the profiles for total COD along the height of the reactor. The equations were adjusted non-linearly (Levenberg-Marquardt algorithm), based on the values of the profiles for each operational phase. Figure 3 shows the COD profiles, including the fit of the first-order kinetic model to the experimental data.

The equation for the first-order kinetic model ($S=S_0e^{-kt}$) was adjusted non-linearly, based on the values of the profiles for each operational phase (Phases II and III). The value of the kinetic coefficient (k) for the above model was estimated at 0.041 h^{-1} and 0.077 h^{-1} for phases II and III respectively.

The values for k found in the literature vary widely depending on the treatment systems, their configuration, the adjusted models and the characteristics of the treated wastewater (BRASIL *et al*., 2007; CHAGAS *et al*., 2011; FIA *et al*., 2012; KADLEC; WALLACE, 2008; MATOS; FREITAS; BORGES, 2011), making comparison difficult between the various related studies.

With the increase in the applied OLR_w, an increase can be seen in the value of the kinetic coefficient obtained during both phases. Increases in the amount of substrate in the reactor resulted in faster conversion rates, leading to the conclusion that there was no limitation on the metabolism of the microorganisms. The higher value for the kinetic coefficient in phase III was expected, since this parameter is directly proportional to the performance of the reactor, i.e. the higher the value of k, the greater the speed of the reaction and, consequently, the greater the efficiency of the reactor. The first-order kinetic model proved to be satisfactory for the two phases of the experiment, presenting values for the coefficient of determination (R^2) of 0.9378 and 0.9720 for phases II and III respectively.

Figure 3 - Adjustment of the profiles obtained in the HAR for the first-order kinetic model, operating during phase II (a) and phase III (b)



In addition to the first-order kinetic model, other modified first-order models found in the literature were fitted to the data, namely: first-order model with residuals, first-order model with delay, and first-order model for tanks in series. Of the models under analysis, the first-order model with delay required the least adjustment of the equation to fit the data, with R^2 values of 0.7351 and 0.7916 for phases II and III respectively. The other two models had values for k and R^2 that were similar to the first-order kinetic model for both phases.

According to Fogler (2008), models with many parameters can be fitted to a wide variety of experimental data, and in these cases, the modelling process is nothing more than simply adjusting the curve. The same author states that in the case of models with similar performance, more-simplified models with fewer variables should always be chosen. Thus, for the case under analysis, it can be inferred that the classic first-order model fitted the data well.

The adjusted profiles afforded a better understanding of the decay pathways during the HRT of 48 and 24 hours (phases II and III), in addition to allowing the decay parameters of the organic matter to be obtained. Using simplified methodology, Moraes and Paula Junior (2004) verified the biodegradability of pig waste, with the aim of assessing the applicability of anaerobic processes. The trials were carried out with batch reactors, using wastewaters and sludges from two sources: UASB treating swine effluent, and UASB treating the effluent from a poultry slaughterhouse. For the trials with swine effluent and unadapted sludge from the poultry slaughterhouse, swine effluent and adapted sludge from the poultry slaughterhouse, and swine effluent and swine sludge, the values for the first-order kinetic coefficient (k) were 0.0249 h^{-1}, 0.0309 h^{-1} and 0.0409 h^{-1} respectively. It should be noted that the value for k of the swine effluent when using swine sludge was close to the value found in phase II of the present study. The value for k in phase III of the present study proved to be higher than those found by Moraes e Paula Junior (2004).

The reactor therefore operated as a compact system, functioning well as a proposed treatment for swine wastewater, where the applied organic load may even be increased. The system afforded the efficient removal of organic material and solids that was adequate for anaerobic reactors, with the advantage of using a unit having a good benefit to cost ratio.

CONCLUSIONS

According to the results, it can be concluded that:

1. Operating under field conditions, occasionally subjected to fluctuations in the temperature of the liquid, and the hydraulic and organic loads, the hybrid anaerobic reactor used in this study remained stable, showing a balance between its efficiency for organic-matter removal and for maintaining the pH of the effluent above 6.5, confirming its stability;
2. System performance can be considered satisfactory, with a mean COD_T removal efficiency after stabilisation greater than 70% and a mean COD_F removal efficiency greater than 80%;
3. The increase in OLR_w and in the applied flow did not affect the ability of the reactor to remove organic material, there being no significant difference between the two operating phases of the system;
4. The first-order kinetic model adequately described the decay kinetics of the organic matter inside the reactor. Increases in the amount of substrate inside the reactor resulted in higher conversion rates for the organic matter.

ACKNOWLEDGEMENT

This study was partially funded by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) under finance code 01.

REFERENCES

AMERICAN PUBLIC HEALTH ASSOCIATION. **Standard methods for examination of water and waste water**. 23rd. ed. Washington: APHA, 2017.

ARAÚJO, I. S. *et al.* Avaliação de sistema de tratamento de dejetos suínos instalado no estado de Santa Catarina. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 16, p. 745-753, 2012.

BRASIL, M. S. *et al.* Modeling of pollution removal in constructed wetlands with horizontal subsurface flow. **Agrartechnische Forschung-Agricultural Engineering Research**, v. 13, n. 2, p. 48-56, 2007.

CHAGAS, R. C. *et al.* Cinética de remoção de matéria orgânica em sistemas alagados construídos cultivados com lírio amarelo. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 15, p. 1186-1192, 2011.

CHENG, D. L. *et al.* Problematic effects of antibiotics on anaerobic treatment of swine wastewater. **Bioresource Technology**, v. 263, p. 642-653, 2018.

DOTRO, G. *et al.* **Treatment Wetlands**. Londres: IWA, 2017.

FIA, F. R. L. *et al.* Remoção de matéria orgânica e determinação de parâmetros cinéticos em sistemas alagados construídos em escala laboratorial. **Acta Scientarum. Technology**, v. 34, n. 2, p. 149-156, 2012.

FOGLER, H. S. **Elementos de engenharia das reações químicas**. Rio de Janeiro: Editora LTC, 2008.

GUPTA, P.; SREEKRISHNAN, T. R.; SHAIKH, Z. A. Evaluating the effects on performance and biomass of hybrid anaerobic reactor while treating effluents having glucose with increasing concentrations of 4-chlorophenols. **Journal of Environmental Chemical Engineering**, v. 6, n. 2, p. 2643-2650, 2018.

KADLEC, R. H.; WALLACE, S. D. **Treatment Wetlands**. 2. ed. Florida: CRC Press, 2008.

LATIF, M. A. *et al.* Integrated application of upflow anaerobic sludge blanket reactor for the treatment of wastewaters. **Water Research**, v. 45, n. 16, p. 4683-4699, 2011.

LEE, C.-Y. *et al.* Performance of subsurface flow constructed wetland taking pretreated swine effluent under heavy loads. **Bioresource Technology**, v. 92, n. 2, p. 173-179, 2004.

LIM, S. J.; FOX, P. A kinetic evaluation of anaerobic treatment of swine wastewater at two temperatures in a temperate climate zone. **Bioresource Technology**, v. 102, n. 4, p. 3724-3729, 2011.

LIU, H. *et al.* Chemical inhibitors of methanogenesis and putative applications. **Applied Microbiology and Biotechnology**, v. 89, n. 5, p. 1333-1340, 2011.

MATOS, A. T.; FREITAS, W. S.; BORGES, A. C. Estudo cinético da remoção de matéria orgânica de águas residuárias da suinocultura em sistemas alagados construídos cultivados com diferentes espécies de vegetais. **Engenharia Agrícola**, v. 31, p. 1179-1188, 2011.

MONTALVO, S. *et al.* Assessment of a UASB reactor with high ammonia concentrations: effect of zeolite addition on process performance. **Process Biochemistry**, v. 49, n. 12, p. 2220-2227, 2014.

MORAES, L. M.; PAULA JUNIOR, D. R. Avaliação da biodegradabilidade anaeróbia de resíduos da bovinocultura e da suinocultura. **Engenharia Agrícola**, v. 24, p. 445-454, 2004.

MORTEZAEI, Y.; AMANI, T.; ELYASI, S. High-rate anaerobic digestion of yogurt wastewater in a hybrid EGSB and fixed-bed reactor: optimizing through response surface methodology. **Process Safety and Environmental Protection**, v. 113, p. 255-263, 2018.

RAVICHANDRAN, P.; BALAJI, K. Effect of HRT on performance of hybrid upflow anaerobic sludge blanket (HUASB) reactor using bio balls in treatment of pulp and paper mill bagasse wash water. **Materials Today: Proceedings**, v. 22, pt 3, p. 627-632, 2019.

SHEPHERD, H. L. *et al.* Time-dependent retardation model for chemical oxygen demand removal in a subsurface-flow constructed wetland for winery wastewater Treatment. **Water Environment Research**, v. 73, p. 597-606, 2001.

WOLFF, D. B.; PAUL, E.; COSTA, R. H. R. Influência do tipo de material suporte no desempenho de reatores biológicos de leito móvel na remoção de carbono e nitrificação de esgoto sanitário. **Engenharia Sanitaria e Ambiental**, v. 15, p. 149-154, 2010.

YU, H. Q.; ZHAO, Q. B.; TANG, Y. Anaerobic treatment of winery wastewater using laboratory-scale multi- and single-fed filters at ambient temperatures. **Process Biochemistry**, v. 41, n. 12, p. 2477-2481, 2006.