http://dx.doi.org/10.1590/1678-4162-12588

(cc) BY

Arq. Bras. Med. Vet. Zootec., v.74, n.4, p.662-670, 2022

Evaluation of the efficiency of anaerobic reactors in the removal of pollutants from fish processing effluents

[*Avaliação da eficiência de reatores anaeróbios na remoção de poluentes em efluentes do processamento de pescado*]

R.R. *Sampaio*[1], S.R. *Sousa*[1], L.S. *Rodrigues*[2], I.J. *Silva*[2]

[1] Graduate, Universidade Estadual Paulista, UNESP, Jaboticabal, SP, Brasil
[2]Universidade Federal de Minas Gerais, Escola de Veterinária, Belo Horizonte, MG, Brasil

ABSTRACT

The objective of the present work was to evaluate the performance of a compartmentalized anaerobic reactor (CAR) followed by anaerobic filter in real scale, effluent treatment from fish fridge processing. The work was developed in a fish fridge located in the south of the state of Minas Gerais, which has an effluent treatment plant composed of static screen, grease removal device, CAR reactor and anaerobic filter. The monitoring happened trough physical-chemical parameters of fluids and effluents from all sampling points of the plant biweekly. The parameters evaluated were temperature, pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), volatile suspended solids (VSS), volatile fatty acids (VFA) and alkalinity. Operational problems found in the primary treatment were not limiting for the system performance, which managed to meet the parameters of environmental legislation in Minas Gerais according to the efficiency of removal of COD, BOD and VSS from wastewater from fish processing.

Keywords: agroindustry, environmental impact, anaerobic digestion

RESUMO

O presente trabalho teve como objetivo avaliar o desempenho de reator anaeróbio compartimentado (RAC) seguido por filtro anaeróbio em escala real tratando efluentes do processamento de frigorífico de pescado. O trabalho foi desenvolvido em um frigorífico de pescado localizado no sul do estado de Minas Gerais, que possui uma estação de tratamento de efluentes composta por peneira estática, caixa de gordura, reator ABR e filtro anaeróbio. O monitoramento do sistema consistiu em um conjunto de análises físico-químicas dos afluentes e efluentes de todos os pontos de coleta de amostras da estação de tratamento coletados quinzenalmente. Os parâmetros avaliados foram temperatura, pH, demanda química de oxigênio (DQO), demanda bioquímica de oxigênio (DBO), sólidos suspensos totais (SST), sólidos suspensos voláteis (SSV), ácidos voláteis totais (AVT) e alcalinidade. Problemas operacionais encontrados no tratamento primário não foram limitantes para o sistema, que conseguiu atender parâmetros da legislação ambiental de Minas Gerais quanto à eficiência de remoção de DQO, DBO e SSV das águas residuárias do processamento de pescado. O sistema de tratamento é uma alternativa promissora para o tratamento de efluentes do processamento de pescado.

Palavras-chave: agroindústria, impacto ambiental, digestão anaeróbia

INTRODUCTION

The world production of fish reached approximately 376 million lbs in 2016 with aquaculture representing 53% of the total fish destined for human consumption. Annual per capita fish consumption is forecast to reach 47.3 lbs by 2030. According to the FAO State of World Fisheries and Aquaculture 2020 report, aquaculture has grown by 5.3% per year since 2000. Brazil occupies the 13th place in the general ranking of the largest fish producers with

Corresponding author: renatar.sampaio@yahoo.com.br
Submitted: October 24, 2021. Accepted: January 12, 2022.

a production of 1.33 million lbs (The state.., 2020). Even if the polluting potential of aquaculture cannot be compared with the polluting potential of some industrial activities in terms of the impact generated, it is necessary for a better management of water resources to improve production, making it socially and ecologically correct in all parts process for the maintenance and integrity of coastal and inland ecosystems. Although these concepts have gained strength and responsibility in recent years, there is still a deficit in assessing the sustainability of aquaculture activities.

The effluent produced during fish processing is rich in organic matter such as blood, viscera, and scales, which can cause damage to water quality when discharge is released indiscriminately. What makes it necessary to study alternatives for the treatment of effluents from this activity.

Anaerobic digestion is a promising alternative in the biological treatment of different kinds of wastewater. The process takes place in the absence of free oxygen and includes various physical, chemical, and biological processes during digestion. This treatment technology has great advantages such as low energy consumption, great efficiency in reducing organic load, small sludge production, among others (Chernicharo, 1997; Ming *et al*., 2016).

The treatment methods applied to liquid effluents must adapt them to current legislation and the quality of the water body that will receive this wastewater, in addition to reducing inputs and energy in this treatment. The compartmentalized anaerobic reactor (CAR) appears as an important option in the treatment of agricultural effluents. This reactor is made up of several compartments where the influent passes through regions of dense microbial population (sludge blanket), always in the upward direction, allowing a greater performance of the microorganisms that degrade the organic matter present.

According to Silva and Nour (2005) and Reynaud and Buckley (2016), this type of reactor has advantages in the treatment of agricultural effluent in the removal of organic matter and suspended solids, in addition to favoring microorganisms in the reactor chambers, avoiding hydraulic shocks such as temperature, pH, organic load and the presence of toxic materials.

Some studies have been carried out on the treatment of fish processing waste, so this work aims to study the performance of the Reactor (CAR) in the removal of organic matter and solids from the liquid waste of a fish processing industry under real operating conditions.

MATERIALS AND METHODS

This search work was developed in a fish slaughterhouse located at the south of the state of Minas Gerais, operating on a full scale. The plant is located beside the Furnas reservoir and encompasses the entire production chain, from the reproduction of tilapia to fattening or rearing in network tanks.

The plant comprises a WTP (Water Treatment plant) in charge of treating the water collected in the Furnas reservoir. The WTP comprises the steps of coagulation, flocculation, decantation, and disinfection. It also has a wastewater treatment plant (WWTP) consisting of a static screen, grease removal device, equalization tank, (CAR) and anaerobic filter Fig.1. The WWTP is responsible for treating all the effluent from the fish processing part before being released into the Furnas reservoir. The effluent is sent for treatment by gravity through a hydraulic pipe.

To start the anaerobic treatment system, the reactor (CAR) was inoculated with 40m^3 of sludge from a UASB reactor (Upflow Anaerobic Sludge Blanket) that treated the effluent of the aforementioned slaughterhouse in November 2012. The sludge was left to rest for a period of approximately 48 hours. After the rest ended, the system started to be fed with approximately 15 m^3 of effluent from the refrigerator for 15 days, with a frequency of three times a week, with a gradual increase until completing 120 days, when the system started to fully operate.

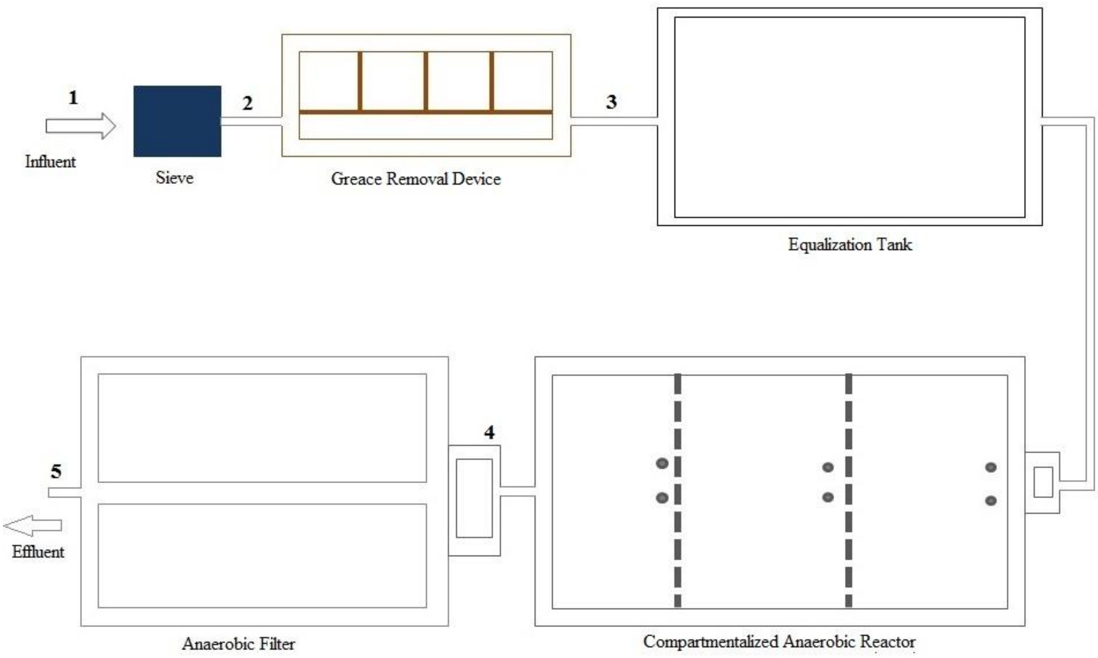

Figure 1. Schematic representation of the fish processing industry's effluent treatment plant and indication of sampling points (1 to 5).

The monitoring program was carried out fortnightly through physical-chemical analyzes Table 1. The sampling was collected at the entrance and exit of the static screen, grease removal device, CAR reactor and anaerobic filter.

The analysis was performed at the Environmental Sanitation Laboratory of the UFMG Veterinary School. The operating conditions of the system are described in Table 2.

The physicochemical analysis was performed as described in the Standard Methods for Examination of Water and Wastewater (Standard…, 2017).

Table 1. Analysis and frequency of monitoring of the ETS

Analysis	Frequency
Temperature	Daily
pH	Fortnightly
Total, partial, and intermediate alkalinity	Fortnightly
Total volatile acids	Fortnightly
Biochemical Oxygen Demand (BOD)	Fortnightly
Chemical Oxygen Demand (COD)	Fortnightly
Filtered Chemical Oxygen Demand (COD filt)	Fortnightly
Particulate Chemical Oxygen Chemical (COD part)	Fortnightly
Total suspended solids (TSS)	Fortnightly
Volatile suspended solids (VSS)	Fortnightly

Table 2. System operating conditions

Parameters	Reactor (CAR)	Anaerobic Filter
Q (L s^{-1})	48	46
HRT (Day)	2.2	1.1
COD (mg L^{-1})	1,320	543
OLR (g COD L d^{-1})	0.6	0.4

Q: flow rate applied to the compartmented anaerobic reactor; HDT: hydraulic Retention time; COD - Chemical Oxygen Demand; OLR - organic load rate.

The collected samples were packaged and transported to maintain their characteristics until the laboratory. Then, they were cooled and kept under refrigeration until the moment of analysis.

The monitoring of the effluent treatment system allowed the effluent to be compared with the standards of environmental legislation, calculate the polluting load, and evaluating the system globally, including the efficiency of each step of the process.

The effluent treatment system was built to operate on a full scale. The grease removal device was built with a useful volume of 2.9m^3, the equalization tank with a useful volume of 54.7m^3, the CAR with a useful volume of 100.8m^3 and the anaerobic filter with a useful volume of 50, 9m^3. The WWTP was designed to process six tons of fish/day, with an expected flow of influent to 150 m^3 d^{-1}. The ascent speed of the system was maintained at 0.8m h^{-1}.

RESULTS AND DISCUSSION

Table 3 shows the mean values, standard deviation and removal efficiency of the physicochemical parameters evaluated during the monitoring time of the influent and effluent of the screen, grease removal device, CAR reactor and anaerobic filter.

During system monitoring, the average temperature was 20 ºC and it was noted that the reactors operated between the psychrophilic (4 to 15°C) and mesophilic (20 to 45°C) ranges, these ranges being suitable for the anaerobic process of organic degradation, but below the optimal temperature range for anaerobic digestion, as cited by (Chernicharo 1997).

The temperature in the anaerobic digestion process is very important for the balance of digestion (Pap *et al*., 2015). According to Van Haandel and Lettinga (1994) the digestion rate decreases approximately 11% for each 1°C of temperature reduction. Rizvi *et al*. (2015) reports that it is possible to find the process of anaerobic digestion at different temperatures, which is responsible for influencing the metabolism of microorganisms, thus promoting their decline or increase.

The screen had a low efficiency in the average removal of CODt from 1,715 to 1,327mg L^{-1}. The speed with which the effluent was sent to the screen caused a sludge carrying into the system. Consequently, the grease removal device had negative results in some samples, that is, the amount of organic matter at the exit of the grease removal device was greater than that at the entrance. This confirms that there was sludge escape because of the high speed of the influent in the sieve, showing that the grease removal device was releasing sedimented material. The average values of CODt removal efficiencies in the system ranged from 11.31 to 53.77%, with most removal observed in the CAR reactor. In some phases of the treatment, such as in the grease removal device, there were no removals due to the dragging of suspended solids from the sludge blanket.

The efficiency of CODt removal in the system was satisfactory, 74.22%, showing that even with the operational problems found in the screen and grease removal device, the system complied with the current environmental legislation, Joint Normative Deliberation COPAM CERH-MG Nº. 01, of 05 of May (Minas Gerais, 2008), which establishes as a maximum limit the value of up to 180 mg L^{-1}, or this limit can only be exceeded when the system presents treatment with efficiency of reduction of COD of at least 70%.

Table 3. Average values (mg L^{-1}) BOD, COD_{total}, $COD_{filtered}$, $COD_{particulate}$, TSS e VSS, standard deviation, removal efficiency and coefficient of variation of the influent and effluents from the sieve, grease trap, CAR reactor and anaerobic filter

	Influent	Sieve	Greace Removal Device	CAR	Anaerobic Filter	Eficiciency Global (%)
BOD	658±182	386±231	683±668	258±118	169±104	-
Efic.(%)	-	43.78	-71.55	52.51	45.39	73.26
c.v.(%)	27.71	59.78	97.82	47.70	61.76	-
COD_t	1715±1250	1327±790	1320±925	543±281	371±242	-
Efic.(%)	-	11.31	-1.83	53.77	30.03	74.22
c.v.(%)	72.86	59.57	70.10	51.86	65.38	-
COD_{filt}	324±281	313±263	253±190	369±300	193±134	-
Efic.(%)	-	1.17	32.59	-52.53	37.47	21.79
c.v.(%)	86,76	83,91	74,93	81,33	69,69	-
COD_{part}	1515±1013	1014±819	1194±874	353±253	234±202	-
Efic.(%)	-	33.31	16.12	68.44	3.53	78.44
c.v.(%)	87.33	81.85	116.23	91.48	112.69	-
TSS	388±269	194±187	431±222	190±110	102±78	-
Efic.(%)	-	40.20	-33.43	31.25	42.50	47.56
c.v.(%)	69,31	111,99	174,27	57,79	77,17	-
VSS	382±277	189±187	420±177	157±101	100±82	-
Efic.(%)	-	34.22	-77.04	40.01	38.02	50.68
c.v.(%)	68.38	110.08	188.28	64.17	81.63	-

BOD - Biochemical oxygen demand; COD_t - total chemical oxygen demand; COD_{filt} - filtered chemical oxygen demand; COD_{part} - particulate chemical oxygen demand; TSS – Total Suspended Solids; VSS – Volatile Suspended Solids.

The CAR reactor showed a DQO particulate removal efficiency of 68.44%, whereas the efficiency of COD filtered was not satisfactory, at -52.53%. This result indicates that part of the material directed to the CAR underwent hydrolysis, thus resulting in an increase in the concentration of dissolved material. The negative efficiency indicates that the biological part of the CAR reactor was inferior, due to the loss of sludge in the system. However, the biological filter managed to remove 37.47% of COD filtered even if the low removal in the CAR Tab 1 reactor.

The influent BOD value found in this study ranged from 408 to 918 mg L^{-1}, like the values reported by Ferracioli, Luiz and Naval (2017) which ranged from 487 to 1350 mg L^{-1} in fish processing effluent. Fig. 2 shows the time series of the monthly mean values of BOD and COD. It is possible to observe the variation in the influent and effluent values of the treatment plant during the experimental period, as well as the reduction in the concentration of the parameters observed when passing through the CAR reactor and anaerobic filter treatment units.

The overall efficiency of the system for BOD was 73.26%, the legislation recommends removal of at least 75%. If we consider the efficiency of the reactor\filter system, disregarding the primary treatment, the efficiency will be 75.25%, greater efficiency than that obtained in the system. Thus, evaluating only the efficiency of the reactor-filter system, it would comply with current legislation. The values of solids showed a big variability in the system, the solids (TSS and VSS) decreased in the screen and increased the concentration in the grease removal device. The operating conditions imposed on the screen and grease removal device promoted significant differences in the quality of the effluent for the concentrations of TSS and VSS, the effluent in the grease removal device had a higher solids value. The difference in the value of 431 mg L^{-1} in the grease removal device to 102 mg L^{-1} in the filter and from 420 mg L^{-1} in the grease removal device to 100 mg L^{-1} in the TSS and VSS filter respectively indicate the occurrence of hydrolysis in the system, that is, the transformation of dissolved material for the use of bacteria. This fact explains the increase in COD filtered in CAR. Cristovão *et al*. (2014) found values between 324 to 3150 mg L^{-1} of TSS and 315 to 2680 mg L^{-1} of VSS in effluent from a canned fish processing industry, suggesting that the high variability in suspended solids concentration was due to the large variability in the effluent composition.

The results of TSS and VSS removal in this study indicated that with the anaerobic treatment system, consisting of a CAR reactor followed by post-treatment with a biological filter, it was possible to obtain mean values of TSS and VSS removal efficiencies of 47.56 % and 50.6% respectively. Considering the removal efficiency of the reactor/filter system only, this was 77% for TSS and 76% for VSS.

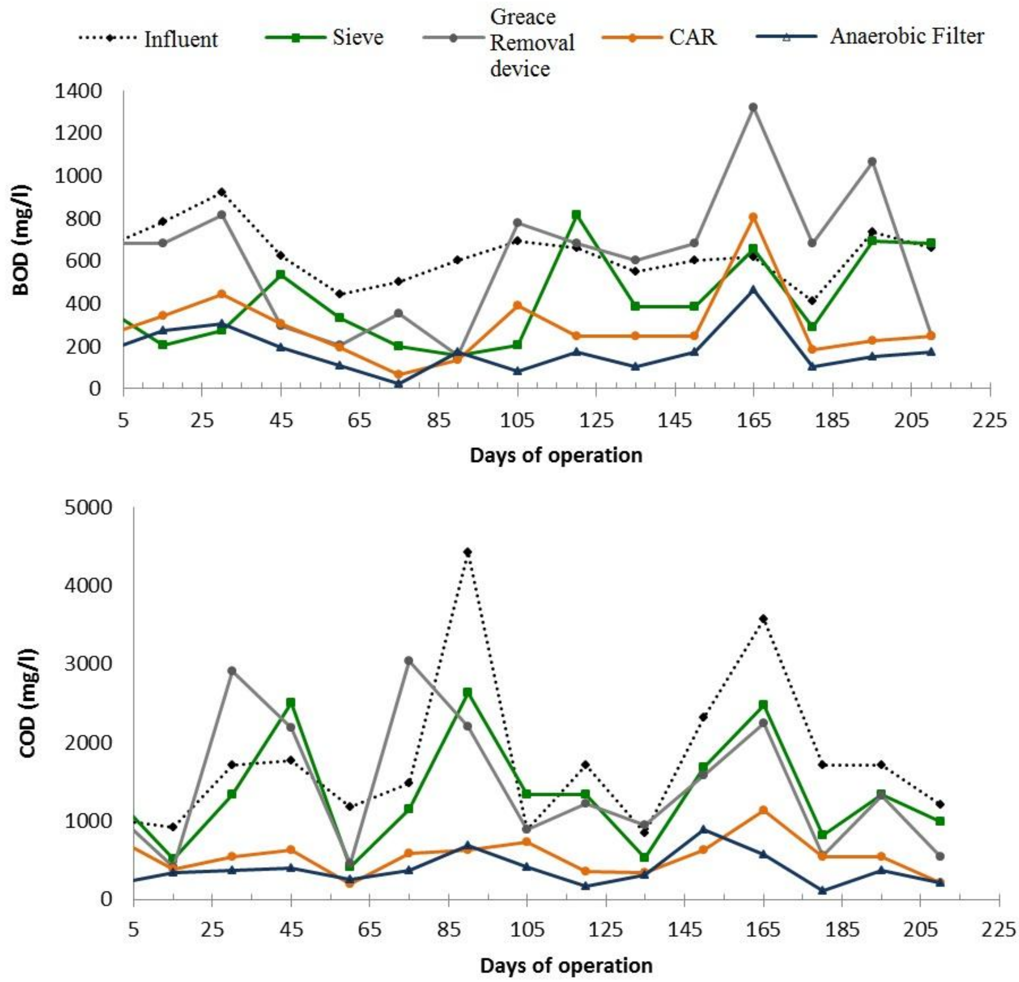

Figure 2. Time series of monthly mean values of BOD and COD.

According to Sperling (1996), for digested sludge, the VS/TS ratio is between 0.60 and 0.65. In this study, this relationship had a mean value of 0.83. According to CONAMA Resolution No. 375 of August 29, (Brasil, 2005), for agricultural use purposes, this ratio must present a value lower than 0.7, a higher value indicates the non-stabilization of the sludge in the reactor. This fact may have occurred due to the constant drag out of sludge in the system.

The average values of pH Tab. 4 showed to increase from the entry of the influent until its exit from the system. According to Letinga and Hulshoff-Pol (1991) most anaerobic treatment systems are operated with pH in the range of 6.5 to 7.5, ensuring the optimal range for methanogenic arquea activities (Sakar *et al.*, 2009).

Table 4. Average values of alkalinity and total volatile acids, standard deviation and pH in the influent and effluents from the sieve, grease removal device, CAR reactor and anaerobic filter

	Influent	Sieve	Grease Removal Device	CAR	Anaerobic filter
pH	5.96±0.39	6.02±0.64	6.02±0.35	6.08±0.42	6.36±0.42
c.v. (%)	6.61	10.68	5.87	6.96	6.59
TA (mg L^{-1})	91±91	61±37	165±64	189±41	242±52
c.v. (%)	100.5	59.90	37.60	21.85	21.61
VFA (mg L^{-1})	188±179	101±38	250±137	150±35	85±35
c.v. (%)	95.37	37.75	54.64	23.26	41.45
IA\PA	2.31	7.91	6.66	3.58	1.06

pH – hydrogenic potential; TA - Total alkalinity; VFA –Volatile Fatt Acids; IA/PA – Intermediate alkalinity/partial alkalinity ratio.

The low pH values are generally related to high concentrations of volatile acids which in turn can make the system unfeasible. Although stability can occur in the formation of methane in a pH range from 6.0 to 8.0, not using volatile acids can lead the system to an imbalance situation. The waste such as fish has a high organic content due to high concentrations of protein (pieces of meat), fat, blood, gut remains, among others, when this type of waste is degraded by the anaerobic digestion process, fatty acids can accumulate in the system (Gebauer, 2004; Gebauer and Eikebrokk, 2006; Kafle and Kim 2013; Nges *et al.*, 2012; Jayashree *et al*., 2016).

Instead of the increasing pH values, these showed a instability Fig. 3 which demonstrates that there were disturbances in the system that may have caused an accumulation of volatile fatty acids, causing a drop in pH values.

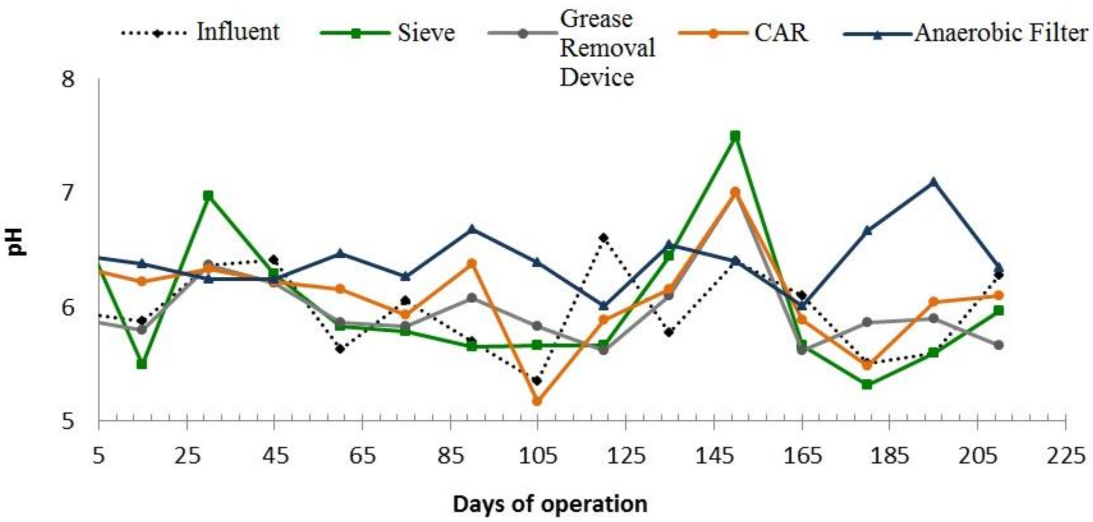

Figure 3. Variation of pH throughout the system.

The total alkalinity increased from 91 to 292mg L^{-1} of the influent to the anaerobic filter respectively during the treatment, thus evidencing the system's buffering tendency. Monitoring bicarbonate alkalinity, that is, partial alkalinity, is more relevant than pH control, as a decrease in pH would imply a greater consumption of alkalinity to maintain system balance, which could lead to a significant decrease of the buffer capacity. The results of the IA/PA ratio found in this research exceeded the value of 0.3 proposed by Ripley *et al.* (1986), which would show an imbalance in the system, but gradually the values decreased over time. This result was important, as it demonstrated that the system withstood the operational failures found in the sieve and grease trap. According to Foresti (1994) and Barros *et al.* (2017) stability in the anaerobic digestion process can occur with values different from 0.3 in different systems.

Santana Junior *et al.* (2019) obtained operational stability and 80% efficiency in COD removal with IA/PA values above those indicated by Ripley *et al*. (1986) from (0.3) operating an anaerobic system treating vinasse.

In general, the acidity decreased from the entrance of the grease box to the exit of the filter. The partial alkalinity was inversely presented, it was increasing in all phases of the treatment, which demonstrated that the system maintained a tendency to become stable, since the reduction in the concentration of acids indicated that these were used by bacteria, not allowing thus its accumulation in the system.

It was found that the VFA values decreased throughout the system as showed in Tab. 4 and there was an increase in the alkalinity values during the effluent treatment, however there was an accumulation of volatile acids and the pH, although showing an increase, remained slightly acid, thus showing that in the initial phases of the treatment when the pH was lower, there was formation of non-ionized volatile fatty acids, that is, in their toxic form.

The removal of the concentration of volatile fatty acids (from 188 to 85 mg L^{-1}) indicated that there was not separation of the acetogenic and methanogenic phases, evidencing a balance of microbial communities in the system, which resulted in good degradability of organic matter and these acids are generally transformed into methane and carbon dioxide in the anaerobic digestion not acidifying the medium through iron accumulation.

CONCLUSION

The system proved to be promising for the treatment of effluents from the fish processing industry, evidencing the need for a better evaluation and adjustments in some stages of the WWTP for better performance of the treatment system. The treatment plant showed better physical efficiency compared to biological, a consequence of the primary treatment, sieve, and grease trap. The speed with which the effluent was directed to the sieve resulted in sludge being carried into the system. As an alternative to improve the WWTP, before the sieve, an equalization tank or a storage box can be included to maintain a constant flow and adequate upward speed, so as not to overload the biological system. Even with the operational failures found during the study, the anaerobic system managed to obtain good values for the removal efficiency of organic matter and solids, (which is extremely important for the energy use of this process) in addition to meeting some of the parameters of environmental legislation in Minas Gerais as to the efficiency of removal and the obtainment of possible organic fertilizer.

REFERENCES

BARROS, V.G.; DUDA, R.M.R.; VANTINI, J.S. *et al*. Improved methane production from sugarcane vinasse with fi lter cake in thermophilic UASB reactors , with predominance of Methanothermobacter and Methanosarcina archaea and Thermotogae bacteria. *Bioresour. Technol*., v.244, p.371-381, 2017.

BRASIL. Conselho Nacional do Meio Ambiente. Resolução Conama nº 357, de 18 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. Brasília, DF. 2005.

CHERNICHARO, C.A.L. *Reatores anaeróbios* - princípios do tratamento biológico de águas residuárias. 2.ed. Belo Horizonte: UFMG. 1997. v.5, p.198.

CRISTÓVÃO, R.O.; BOTELHO, C.M.; MARTINS, R.J. *et al*. Primary treatment optimization of a fish canning wastewater from a Portuguese plant. *Water Resour. Ind.*, v.6, p.51-63, 2014.

FERRACIOLLI, L.M.R.V.D.; LUIZ, D.B.; NAVAL, L.P. Potential for reuse of effluent from fish-processing industries. *Rev. Ambient. Água*, v.12, n.5, 2017.

FORESTI, E. Fundamentos do processo de digestão anaeróbia. TALLER Y SEMINÁRIO LATINOAMERICANO: TRATAMENTO ANAERÓBIO DE ÁGUAS RESIDUAIS, 3., 1994, Montevideo. *Anais*... Montevideo: [s.n.], 1994. p.97-110.

GEBAUER, R. Mesophilic anaerobic treatment of sludge from saline fish farme ffluents with biogas production. *Bioresour. Technol*., v.93, p.155-167, 2004.

GEBAUER, R.; EIKEBROKK, B. Mesophilic anaerobic treatment of sludge from salmon smolt hatching. *Bioresour. Technol*., v.97, p.2389-2401, 2006.

JAYASHREE, C.; TAMILARASAN, K.; RAJKUMAR, M. *et al*. Treatment of seafood processing wastewater using upflow microbial fuel cell for power generation and identification of bacterial community in anodic biofilm. *J. Environ. Manag*., v.180, p.351-358, 2016.

KAFLE, G.K.; KIM, S.H. Anaerobic treatment of apple waste with swine manure for biogas production: Batch and continuous operation. *Appl. Energy*, v.103, p.61-72, 2013.

LETTINGA, G.; HULSHOFF-POL, L.W. UASB: process design for various types of wastewaters. *Water Sci. Technol*., v.24, p.87-107, 1991.

MINAS GERAIS. Deliberação Normativa Conjunta COPAM/CERH-MG N.º 1, de 05 de maio de 2008. Diário executivo de Minas Gerais de 17 de mar. 2008. *Diário Oficial de Minas Gerais*, Poder Executivo, Belo Horizonte, MG de 13 de maio 2008.

MING, XU.; LILI, DING.; KE, XU. *et al*. Flow patterns and compartment optimization for the anaerobic reactor. *Desalin. Water Treat*., v.57, p.345-352, 2016.

NGES, I.A.; ESCOBAR, F.; FU, X.; BJÖRNSSON, L. Benefits of supplementing an industrial waste anaerobic digester with energy crops for increased biogas production. *Waste Manag*., v.32, p.53-59, 2012.

PAP, B.; GYÖRKEI, Á.; BOBOESCU, I.Z. *et al*. Temperature-dependent transformation of biogas-producing microbial communities points to the increased importance of hydrogenotrophic methanogenesis under thermophilic operation. *Bioresour. Technol.*, v.177, p.375-380, 2015.

REYNAUD, N.; BUCKLEY, C.A. The anaerobic baffled reactor (ABR) treating communal wastewater under mesophilic conditions: a review. *Water Sci. Technol*., v.73, p.463-478, 2016.

RIPLEY, L.E.; BOYLE, W.C.; CONVERSE, J.C. Improved alkalimetric monitoring for anaerobic digestion of high-strength waste. *J. Water Pollut. Control Fed*., v.58, p.406-411, 1986.

RIZVI, H.; AHMAD, N.; ABBAS, F. *et al*. Start-up of UASB reactors treating municipal wastewater and effect of temperature/sludge age and hydraulic retention time (HRT) on its performance. *Arab. J. Chem*., v.8, p.778-786, 2015.

SAKAR, S.; YETILMEZSOY, K.; KOCAK, E. Anaerobic digestion technology in poultry and livestock waste treatment - A literature review. *Waste Manag. Res*., v.27, p.3-18, 2009.

SANTANA JUNIOR, A.E.; DUDA, R.M.; OLIVEIRA, R.A. Improving the energy balance of the industry of ethanol with methane production from vinasse and molasses in two-stage anaerobic reactors. *J. Cleaner Prod*., v.238, 117577, 2019.

SILVA, G.H.R.; NOUR, E.A.A. Reator compartimentado anaeróbio/aeróbio: sistema de baixo custo para o tratamento de esgotos de pequenas comunidades. *Rev. Bras. Eng. Agríc. Ambient*., v.9, p.268-275, 2005.

SPERLING, M.V. *Princípios do tratamento biológico de águas residuarias.* 2.ed. Belo Horizonte. UFMG, 1996. 108p.

STANDARD methods for the examination of water and wastewater. 21th ed. Washington: American Public Health Association/American Water Works Association/ Water Environment Federation. 2017.

THE STATE of world fisheries and aquaculture 2020. Rome: FAO, 2020. p.244.

VAN HAANDEL, A.C.; LETTINGA, G. *Tratamento anaeróbio de esgotos*: um manual para regiões de clima quente. Campina Grande: Epgraf, 1994. 240p.