REGET/UFSM
Revista Eletrônica em Gestão, Educação e Tecnologia Ambiental
V. 27 2023
ISSN 2236-1170
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REGET, v. 27, e85240, 2023 • https://doi.org/10.5902/2236117085240
Submitted: 29/09/2023 • Accepted: 23/02/2024 • Published: 02/08/2024

Environmental Technology

Batch biodigesters efficiency in anaerobic biodigestion waste of swine

Eficiência de biodigestores batelada na biodigestão anaeróbia de dejetos suínos

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ABSTRACT

The expansion of the pig industry has consolidated this activity among those most negatively impacting the environment. Large volumes of wastewater generated in small units, combined with a lack of technologies and incentives to treat these wastes, make this problem even more serious. Aim to evaluate the removal of parameters Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Fixed Solids (FS), and Volatile Solids (VS), the anaerobic digestion of pig manure using biodigesters batch flow pilot-scale, under the influence of different ambient temperatures during the period of one year (365 days). The statistical design was a randomized block with eight treatments and three repetitions, each treatment a cycle with a hydraulic retention time (HRT) of 40 days. There were two cycles for each season, raw wastewater samples were collected, and each biodigester was treated. There are significant differences between the evaluated cycles. The end efficiencies found for BOD were 81.03% (cycle 5) and 14.86% (cycle 3). For COD, they were 76.07% (cycle 5) and 17.79% (cycle 1). To FS 58.58% (cycle 3) and 15.97% (cycle 6). For VS, it was 86.68% (cycle 7) and 24.75% (cycle 3). The mean efficiency in eight cycles was higher for COD. It was concluded that the anaerobic biodigesters batch pilot-scale was shown to be effective in the treatment of swine waste. However, its efficiency depends on the temperature and the adopted HRT.

Keywords: Pig farming; Wastewater treatment; T

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RESUMO

A expansão da suinocultura consolidou esta atividade entre as que mais causam impactos negativos ao meio ambiente. Grandes volumes de efluentes gerados em pequenas unidades de áreas, aliado a falta de tecnologias e a incentivos para tratamento desses dejetos, tornam essa problemática ainda mais grave. Objetivou-se avaliar a remoção dos parâmetros Demanda Química de Oxigênio (DQO), Demanda Bioquímica de Oxigênio (DBO), Sólidos Fixos (SF) e Sólidos Voláteis (SV), na biodigestão anaeróbia de dejetos suínos utilizando biodigestores fluxo em batelada em escala piloto, sob a influência de diferentes temperaturas ambientes no decorrer de um ano (365 dias). O delineamento estatístico utilizado foi em blocos ao acaso, com oito tratamentos e três repetições, sendo cada tratamento um ciclo com tempo de retenção hidráulica (TRH) de 40 dias. Foram dois ciclos para cada estação do ano, onde foram coletadas amostras de efluente bruto e tratado de cada biodigestor. Ocorreram diferenças significativas entre os ciclos avaliados. Os extremos de eficiências encontrados para DBO foram de 81,03% (ciclo 5) e 14,86% (ciclo 3). Para DQO foram 76,07% (ciclo 5) e 17,79% (ciclo 1). Para SF 58,58% (ciclo 3) e 15,97% (ciclo 6). Para SV foram 86,68% (ciclo 7) e 24,75% (ciclo 3). A média de eficiência nos oito ciclos foi mais alta para a DQO. Concluiu-se que os biodigestores anaeróbios em batelada em escala piloto demonstraram ser eficientes no tratamento de efluentes suínos. Contudo, sua eficiência depende da temperatura e do TRH.

Palavras-chave: Suinocultura; Tratamento de água residuárias; Temperatura

1 INTRODUCTION

Pig farming is characterized by being a significant agricultural activity in Brazil. Over time, there has been a constant growth in the area, causing the country to consolidate itself as the fourth largest producer and exporter of pigs in the world (ABPA, 2021). It has also become a technical activity, endowed with large confinements, with many animals housed in small areas at all stages of the production cycle (Mcauliffe *et al*., 2017; Sousa *et al*, 2022).

A large amount of waste generated is generated during the production process. An example cited by Araujo and Oliveira (2023), reports that a sow with a mass between 25 and 100 kg produces about 7 liters of waste per day. In the case of sows in gestation, this value can reach up to 17 liters per day. These wastes, when handled incorrectly, characterize a serious situation of pollution, causing a significant environmental impact.

The pollution caused by the swine industry added to the problems of domestic and industrial waste has caused severe environmental problems, mainly related to water pollution, due to the high organic load and the presence of fecal coliforms (Araujo; Oliveira, 2023). The high polluting capacity of swine manure is characterized by high concentrations of organic matter, total and thermotolerant coliforms, and nutrients, especially N and P. The use of water in the facilities, used for cleaning the stalls and drinking troughs, contributes to increasing the amount of waste generated (Sousa *et al*., 2022).

The use of waste recycling techniques and processes becomes indispensable, as it reduces the concentration of organic material and the pollution of the waste. Anaerobic biodigestion is a process that minimizes the pollutant load of swine manure and also has the advantage of converting most of the organic bag of the raw and raw fluid into biogas and biofertilizer which can provide the rural property with an extra source of income (Santos; Mayerle; Rodriguez, 2022). Anaerobic digestion is carried out through biochemical reactions that are integrated into several steps of conversion and production of various compounds to obtain methane gas (CH_4) (Leite *et al*., 2023).

Anaerobic biodigesters are a technique for treating swine manure and allow removing a large part of the polluting load of the waste (Paranjpe; Saxena; Jain, 2023). Biodigestion using biodigesters also promotes the reduction of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Fixed Solids (FS) and Volatile Solids (VS).

Knowing that bacteria are not capable of assimilating complex organic matter, the first phase in the anaerobic degradation process, called hydrolysis, consists of the conversion of complex organic materials (polymers), such as proteins, carbohydrates and lipids, through the action of exoenzymes excreted by hydrolytic fermentative bacteria, into simpler dissolved compounds (smaller molecules) that can cross the cell walls of fermentative bacteria, namely amino acids, soluble sugars, long-chain fatty acids and glycerin. The hydrolysis of polymers occurs slowly, with several factors that can affect the degree and rate at which the substrate is hydrolyzed: operating temperature of the reactor, residence time of the substrate in the reactor, composition of the substrate and pH value of the medium (Chernicharo, 1997; Pierotti, 2007).

In the second phase, acidogenesis, the products resulting from hydrolysis are metabolized by fermentative bacteria. Acidogenic microorganisms ferment sugars, amino acids and fatty acids into compounds that include organic acids (acetic, propionic and butyric), alcohols, lactic acids, carbon dioxide, hydrogen, ammonia and hydrogen sulfide, through the action of acidogenic fermentative bacteria (Chernicharo, 1997). These bacteria are strictly anaerobic, however, around 1% are facultative, which is of great importance as they consume the oxygen present in the environment that is toxic to strict anaerobic bacteria. The hydrogen, carbon dioxide and acetic acid produced in this phase skip the 3rd stage of the process and are used directly by methanogenic bacteria in the final phase of the process (Pierotti, 2007).

Acetogenic bacteria are responsible for converting compounds generated in the acidogenic phase, such as propionate and butyrate, into an appropriate substrate for methanogenic bacteria. The products generated are: hydrogen, carbon dioxide and acetate. During the formation of acetic and propionic acids, a large quantity of hydrogen ions is formed, causing the pH value in the aqueous medium to decrease (Pierotti, 2007). About 70% is converted into acetic acid and the remainder into CO_2 and H_2.

The final step of the degradation process, methanogenesis, is carried out by methanogenic bacteria. These use only a limited number of substrates, such as acetic acid, hydrogen, carbon dioxide, formic acid, methanol, methylamines and carbon monoxide (Chernicharo, 1997). Depending on their substrate affinity and magnitude of methane production, methanogens are divided into two main groups, one that forms methane from acetic acid or methanol (acetoclastic), and the second that produces methane from hydrogen and dioxide. carbon (hydrogenotrophic) (Chernicharo, 1997). This complex interaction between different groups of microorganisms is essential for the successful anaerobic biodigestion of swine manure (Do Amaral *et al*., 2019, Basile *et al*., 2020; Araujo, 2022).

This work evaluated the performance of batch digesters built in a small rural swine farm in removing the polluting load from the local effluent, measuring it by analyzing the parameters COD, BOD, FS, and VS. To evaluate the removal of COD, BOD, FS and VS parameters in the anaerobic digestion of swine manure using pilot-scale batch biodigesters under the influence of different temperatures.

2 METHODOLOGY

2.1 Study location

The experiment was carried out in a rural swine production unit located on Linha Piaia de Cézaro, in the municipality of Vista Alegre-RS, situated at latitude 27°22'01'' south and longitude 53°29'25'' west, being at an altitude of 546 meters above sea level.

Knowing the influence of ambient temperature on this type of treatment (Wang, *et al*., 2019), the mean temperature data were obtained from the INMET meteorological station, located at the Federal University of Santa Maria campus Frederico Westphalen, approximately 6 km from the experiment site.

Parameter analyzes to verify the efficiency of the effluent treatment system were carried out in the laboratory located at the Federal University of Santa Maria campus Frederico Westphalen, Rio Grande do Sul.

2.2 Treatment system

Swine waste is essentially made up of: animal feces and urine; feed waste; water, coming from excess water fountains and used for cleaning the facilities; and hair, dust and other materials resulting from the creative process (Konzen, 1983).

The main polluting components of swine manure are nutrients, such as nitrogen (N), phosphorus (P) and some microminerals, such as zinc (Zn) and copper (Cu). In addition to these pollutants, this type of waste is characterized by high loads of organic matter, toxic substances, heavy metals and pathogenic organisms (fecal coliforms, Escherichia coli, among others) (Oliveira *et al*., 2006).

The quantity and quality of waste produced varies with the type of farming, the amount of water used in the facilities, the season of the year, the food and the number and category of animals (Alves, 2007). The quantity and quality of volatile solids (VS) present in waste are the main factors that affect methane production during treatment. Therefore, animal nutrition must be carefully planned to ensure an adequate composition of waste that favors the production of biogas efficiently and sustainably (Souza, 2021). Furthermore, it is known that lactating and pregnant sows produce the largest amount of waste in the pig chain (Souza, 2021). Authors observed higher daily BOD values in sows with piglets, followed by breeding pigs and gestating sows (De Oliveira *et al*., 1993; Freire, 1985).

The experiment lasted 365 days. Three home-made batch-flow biodigesters were made on a pilot scale to carry out the anaerobic fermentation of swine effluent from the matrix of pregnant sows from the own property, to reduce the concentrations of COD, COD, FS and SV of the compound to be degraded and verify the efficiency of the system.

For this, barrels with a maximum capacity of 150 L were used. Each biodigester worked individually, connected only with a water seal to regulate the internal pressure and output of the biogas produced in the process.

At the top of each reactor (biodigester), a 20 mm hole was drilled, and a water seal was installed, regulating the pressure and gas output during the treatment.

After filling the biodigesters, carried out at the beginning of each cycle, it was sealed with the asphalt blanket, and at the end of each cycle, it was removed. The treated effluent was collected for analysis in the laboratory.

The digesters were supplied in eight cycles, all lasting 40 days, the time necessary for stabilizing the manure, seeking to analyze the behavior and efficiency of the system's treatment at different ambient temperatures for a year.

The swine matrix used was from sows in gestation, and the effluent was retained in the pens, sent to a mixing box, where it was homogenized, and 120 L was collected by biodigester.

The division of the cycles was made according to the seasons of the year, Table 1. There were 8 cycles, 2 per season, where the period of the first cycle of the season was from the beginning to the middle of the season and the second cycle from the center to the end of its station. Ambient temperature, an essential factor in compost degradation, was determined daily.

Table 1 – Cycles division

Cycles	Season
1	Winter
2	Winter
3	Spring
4	Spring
5	Summer
6	Summer
7	Autumn
8	Autumn

Source: Organized by the authors

2.3 Verification of treatment efficiency

A sample of raw effluent was collected from each biodigester after being supplied at the beginning of each cycle to carry out the analyses. After 40 days of treatment, samples of treated effluent were collected, also one from each reactor (Seganfredo *et al.,* 2022; IMA, 2021). These samples were collected in plastic flasks to carry out the determinations of BOD, VS and FS parameters and in glass flasks for COD determination, approximately 2 L per sample.

As soon as they were collected, the samples were immediately sent to the laboratory to determine their preservation. Determinations of raw and treated effluent from the 8 cycles were made. The parameters analyzed, were: BOD, COD, VS, and FS (Silva *et al*., 2022).

BOD is an empirical test that corresponds to the difference between oxygen concentrations at the beginning and end of the incubation period under specific assay conditions. For this parameter, the method of dilution and incubation for 5 days at 20 °C was used, in which dissolved oxygen (DO) is determined on the 1st and 5th days by the Winkler method modified by sodium azide (APHA, 2012).

For the analysis of COD of the affluent, the open reflux method with dichromate was used. For VS and FS, the procedure used was the gravimetric method, based on the differences in sample weights after being subjected to evaporation temperatures (APHA, 2012). A summary of the analysis is presented in Table 2.

Table 2 – Parameters and methods used for effluent analysis

Parameter	Method	Reference
BOD	Dilution and incubation method / Method of winkler	APHA (2012)
COD	Open reflux method with dichromate	APHA (2012)
VS	Gravimetri	APHA (2012)
FS	Gravimetri	APHA (2012)

Source: Organized by the authors.
Legend: BOD= Biochemical Oxygen Demand; COD= Chemical Oxygen Demand; FS= Fixed Solids; VS= Volatile Solids

2.4 Statistical analysis

The experimental design used was a completely randomized block where eight treatments (cycles) and three replications (biodigesters) were evaluated, with temperature variation during the seasons being considered an experimental factor. The experiment was based on verifying efficiency in treating COD, BOD, FS, and VS variables.

Knowing the influence of ambient temperature on this type of treatment, the mean temperature data were obtained from the INMET meteorological station, located at the Federal University of Santa Maria campus Frederico Westphalen, approximately 6 km from the experiment site.

The results obtained after collecting samples and analysis in the laboratory were submitted to analysis of variance. The means were compared by Tukey's test, revealing significant differences for the treatment factors and an analysis of variance with 5% probability (Yamada et al., 2023). For statistical analysis, the SAS Learning Edition software was used.

3 DISCUSSION AND RESULTS

The effluent characterization was carried out at the beginning and at the end of the 8 cycles of swine manure treatment in pilot-scale batch biodigesters. Table 3 presents the measures applied in the biodigesters, considering the parameters BOD, COD FS, and VS.

It can be seen from the results of Table 3 that cycles 1 and 2, and both occurred in winter, presented the highest application loads for the parameters BOD, COD, and FS. For VS, the highest load occurred in cycle 7. The quantification of loads removed was performed for the 8 cycles, seeking to verify the treatment of waste applied in the biodigesters about their loads used at the end of the 40 days of HRT. In Table 4, the average results obtained for the BOD parameter.

Table 3 – Characterization of raw effluent from swine manure

Cycle	BOD (mg L^{-1})	COD (mg L^{-1})	FS (mg L^{-1})	VS (mg L^{-1})
1	6,286	10,900	7,833	5,360
2	10.333	16,666	12,070	4,341
3	2,751	6,000	2,292	1,896
4	2,733	5,333	3,800	2,950
5	3,733	10,133	2,425	3,559
6	1,933	4,900	1,917	2,594
7	5,789	14,866	3,830	7,021
8	4,634	7,000	2,633	2,750

Source: Organized by the authors.
Legend: BOD= Biochemical Oxygen Demand; COD= Chemical Oxygen Demand; FS= Fixed Solids; VS= Volatile Solids.

Table 4 –Characterization of BOD

Cycle	BOD input (mg L^{-1})	BOD output (mg L^{-1})	DBO removed (mg L^{-1})	Removed (%)
1	6,286	4,520	1,766	29.18
2	10,333	7,616	2,716	26.25
3	2751	2,333	417	14.86
4	2,733	2,100	633	22.98
5	3,733	700	3,033	81.03
6	1,933	1,133	800	41.55
7	5,789	1,969	3.819	66.06
8	4,634	3,283	1,351	29.22

Source: Organized by the authors
Legend: BOD= Biochemical Oxygen Demand

The highest application rates were in the two winter cycles, and in cycle 2 the average was 10,333 mg L^{-1}. A lower rate occurred in cycle 6, corresponding to 1,933 mg BOD L^{-1}. In the other cycles, the values found ranged between 1,500mg L^{-1} and 6,000 mg L^{-1}.

Cycles 7 and 5 had the highest BOD values. Effluents with a higher applied load have a slower acclimatization time, but if the HRT is increased, the amount of nutrients is not a limiting factor in the process.

Dal Mago (2009) mentions that, in some cases, the removal of BOD may be more significant in periods of lower temperatures. With high loads applied, there are more amounts of microorganisms and thus more removal, all under the influence of ambient temperature. Table 5 presents the values related to the loads for COD.

Table 5 – Characterization of COD (mg L^{-1})

Cycle	COD Input	COD Output	COD Removed	(%) Removed
1	10,900	8,950	1,950	17.79
2	16,666	9,333	7,333	44.15
3	6,000	2,333	3,666	61.11
4	5,333	3,666	1,666	34.44
5	10,133	2,402	7,731	76.07
6	4,900	1,301	3,598	73.49
7	14,866	4,598	10,267	69.2
8	7,000	5,300	1,699	24.23

Source: Organized by the authors
Legend: COD= Chemical Oxygen Demand

The COD application rates varied between 4,900 mg L^{-1}, in cycle 6, and 16,666 mg L^{-1} determined in cycle 2. The highest removals occurred during cycles 7 and 5, similar to the behavior found for BOD. Comparing the highest loads found, cycles 2 and 7, when the temperature is higher, as occurred in cycle 7, the removal increases. Table 6 presents the values in terms of load for the parameters SF and SV.

It is observed that the FS showed the same behavior as the previous variables, BOD and COD, in terms of input load. However, the FS obtained more removal in the cycles operated with cold temperatures, cycles 2 and 1. The VS presented a lower load applied in cycle 3 and greater in cycle 7. This cycle also obtained a more significant amount removed.

Table 6 – Characterization of SF and VS in (mg L^{-1})

Cycle	FS				VS			
	Input	**Output**	**Removed**	**Removed (%)**	**Input**	**Output**	**Removed**	**Removed (%)**
1	7,833	5,673	2,160	27.60	5,360	3,476	1,883	35.32
2	12,070	7,326	4,743	40.77	4,341	2,894	1,446	39.01
3	2,292	933	1,359	58.58	1,896	1,433	463	24.75
4	3,800	1,784	2,015	48.56	2,950	1,847	1,102	35.67
5	2,425	1,946	478	19.30	3,559	1,432	2,126	61.26
6	1,917	1,612	305	15.97	2,594	1,192	1,401	53.97
7	3,830	2,496	1,333	35.43	7,021	935	6,085	86.68
8	2,633	2,003	629	24.04	2,750	1,626	1,123	40.76

Source: Organized by the authors
Legend: VS= Volatiles Solids; FS= Fixed Solids

According to the results obtained in the statistical analysis, significant differences were observed between treatments ($p<0.05$) for all variables evaluated by the Tukey test. The average percentages of reduction of BOD, COD, FS, and VS of the manure in the three reactors in each of the treatments submitted to the different temperatures are presented in Table 7.

As shown in Table 7, it was found that in the periods of higher temperatures, 24.09 °C, and 23.63 °C, there was a greater removal efficiency in the parameters BOD, COD, and VS. Under low temperatures, there was a reduction in efficiency, mainly in the BOD variable. According to Van Haandel & Lettinga (1994), anaerobic digestion is possible at low temperatures (10ºC). However, its efficiency and the organic load are significantly reduced.

In Figure 1, the average ambient temperature obtained in the 40 days of each cycle can be verified. Cycles 5 and 6, both occurring during the summer, had the highest temperature averages. It is also confirmed that cycle 7, in autumn, had its average temperature in the range of 20.13 °C, but with a low average daily thermal amplitude, with no significant variations during the cycle.

Table 7– Means of efficiencies in the treatment of BOD, COD, FS, and VS in pilot-scale batch biodigesters

Cycles	BOD (%)	COD (%)	FS (%)	VS (%)	Average Temperature (°C)*
5	81.03 a	76.07 a	19.30 b	61.26 ab	24.09
7	66.06 ab	69.2 a	35.43 ab	86.68 a	20.13
6	41.55 bc	73.49 a	15.97 b	53.97 bc	23.63
8	29.22 cd	24.23 cd	24.04 ab	40.76 bcd	17.77
1	29.18 cd	17.79 d	27.60 ab	35.32 cd	15.37
2	26.25 cd	44.15 bc	40.77 ab	39.01 bcd	17.59
4	22.98 cd	34.44 cd	48.56 ab	35.67 bcd	23.24
3	14.86 d	61.11 ab	58.58 a	24.75 d	21.98
Average	38.89	50.06	33.78	47.18	-
CV (%)	21.95	16.6	38.76	18. 91	-

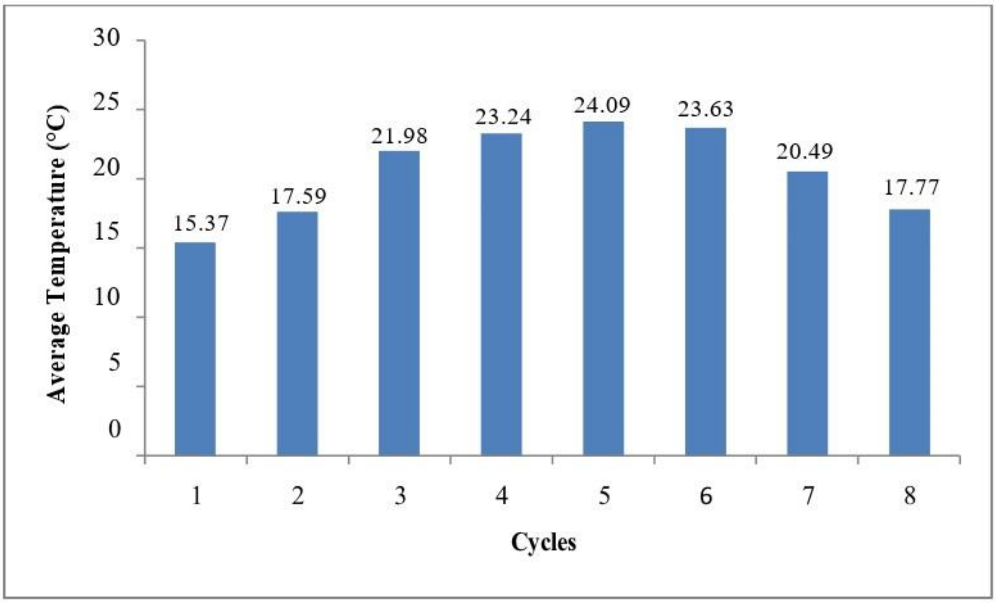
Source: Organized by the authors
*Source: INMET
Legend: CV= coefficient of variance; DBO= Biochemical oxygen demand; DQO= Chemical Oxygen Demand; VS= Volatile Solids; FS= Fixed Solids. Means followed by the same lowercase letter in the column, do not differ by Tukey's test (α=0,05)

According to the statistical analysis, for the BOD variable, cycles 5 and 7 did not differ from each other, obtaining the highest efficiency results. Cycle 6 does not vary from cycle 7 but with a lower average. Cycles 6, 8, 1, 2, and 4 obtained intermediate results and did not differ from each other. Cycle 3 had the lowest value, and its average does not vary from cycles 8, 1, 2 and 4.

The highest BOD removal occurred in cycle 5, which occurred in early summer, with an efficiency of 81.03%. This cycle was the one with the highest average ambient temperature. Also noteworthy is the removal of BOD from cycle 7, in autumn, whose mean found does not differ statistically from cycle 5, but had a lower efficiency with

66.06%. Cycle 6 had an intermediate efficiency in the range of 41.55%. The remaining treatments had lower BOD removals. Cycles 1, 2 and 8 showed low temperatures, which delays the development of microorganisms responsible for anaerobic digestion. Even with high temperatures, cycles 3 and 4 showed lower than expected efficiencies. This case may have occurred due to the action of actors in the biodigestion process, such as the BOD applied in this cycle is difficult to degrade; a rainy season where there is a lot of effluent dilution and material drag (twigs, leaves and soil) or the presence of an inhibitory agent.

Figure 1–Average temperatures of each treatment cycle



Source: Adapted from INMET

The highest BOD removal occurred in cycle 5, which occurred in early summer, with an efficiency of 81.03%. This cycle was the one with the highest average ambient temperature. Also noteworthy is the removal of BOD from cycle 7, in autumn, whose mean found does not differ statistically from cycle 5, but had a lower efficiency with 66.06%. Cycle 6 had an intermediate efficiency in the range of 41.55%. The remaining treatments had lower BOD removals. Cycles 1, 2 and 8 showed low temperatures, which delays the development of microorganisms responsible for anaerobic digestion. Even with high temperatures, cycles 3 and 4 showed lower than expected efficiencies. This case may have occurred due to the action of actors in the biodigestion process, such as the BOD applied in this cycle is difficult to degrade; a rainy season where there is a lot of effluent dilution and material drag (twigs, leaves and soil) or the presence of an inhibitory agent.

The results found for the BOD variable show that temperature is an intervening factor in the treatment. Cycles with high average daily temperatures or without many variations, the ones that obtained better performance concerning the other treatments. Speece (1996) observed that for every 5°C drop in temperature, there is a 34% decline in the activity of microorganisms.

Under suitable conditions, usually, the BOD of swine manure can reach a reduction of up to 90% in concentration after treatment in the biodigester (Kunz *et al*., 2005). Fernandes (2014) found in his work on applying anaerobic digestion in a swine farm an average efficiency of biodigesters for the removal of BOD of 67.38%, a removal rate similar to that found by Orrico Júnior (2007), which was 68.42 %.

Analyzing the COD variable, it is observed that cycles 5, 6, 7, and 3 had no statistical difference between their removal averages, obtaining the highest efficiency results in that order. Cycles 5 and 6 had the highest efficiency averages, 76.07 % and 73.49% respectively, these being the two cycles that occurred in the summer period and with the most elevated average temperatures. Cycle 7 showed removal of 69.2%. Cycle 3 does not differ from cycle 2, but both have lower averages. Cycles 2 do not vary from 4 and 8, and these do not differ from cycle 1, which showed the lowest average efficiency, 17.79 %. In addition, this cycle also obtained the lowest temperatures.

The treatments for COD proved to be more efficient at higher temperatures. The average of all cycles for COD removal was 50.06 %, higher than the average of treatments for BOD, of 38.89 %.

Fernandes (2014) found efficiency of 52.61% in biodigesters for COD removal. The efficiency found by Moretti (2009) was 50.87 % when analyzing the treatment of swine manure in confinement, having used two biodigesters in parallel in its treatment system. The average of these authors is similar to that found in this study, 50.06%.

Volatile solids were similar to the previous variables about cycles with higher efficiencies. Cycle 7 showed higher average efficiency than the others, with 86.68% removal. This cycle does not differ statistically from cycle 5, which had an average of 61.26 %. Cycle 5 does not differ from cycles 6, 8, 2, and 4. These four cycles had intermediate efficiency means and all did not vary from treatments 1 and 3.

The efficiencies of this variable remained similar in all cycles, increasing in periods with higher temperatures. The overall mean of all eight treatments for VS was 47.18 %.

Dal Mago (2009) analyzed the behavior of a series of biodigesters where one of the reactors reached an efficiency of 92 % in the summer, decreasing to 33 to 40 % in the winter and spring periods. Vivan *et al*. (2010) evaluated the performance of biodigesters with temperatures in the range of 22 °C and obtained removal of 34.63 % of volatile solids. Similar behavior was found in this work, where in hot periods, the efficiency reached 86.68 % and, with the temperature drop, these values reduced to the range between 30 and 40 %.

The statistical analysis showed that the FS variable was not influenced by temperature like the others mentioned. It can be seen from the values in Table 6 that this variable behaved differently, having lower FS removal efficiencies in the cycles with higher average temperatures, as is the case of the two processes in the summer period. By the Tukey test, it is noted that cycles 3, 4, 2, 7, 1, and 8 do not differ from each other, these being the cycles that presented the highest efficiency values in the removal of this parameter, in that order respectively. Cycles 5 and 6, both occurring in the summer, differ only from cycle 3 and do not differ from the others. These treatments showed the lowest efficiency rates, 19.30 and 15.97 %.

The general average of the eight cycles of this work was 33.78 %, which is higher than those presented by Vivan *et al*. (2010), which 2.72% FS in treated removal medium and treated effluents from biodigesters.

At the end of some cycles, especially those that occurred at lower temperatures, it was observed that, for the chosen HRT of 40 days, cycles 1, 2, 3 and 8 were still in the fermentation stage, that is, the treatment was incomplete.

In addition, the treated effluent had more cloudy and odorous interpretation characteristics. This may have been because the acclimatization time of the biodigesters at low temperatures, thus being longer for the microbial activity at the beginning. Cycles operated at higher temperatures show different behavior. In cycles 5, 6, and 7, the treated project had no manufacturing characteristics and a more straightforward interpretation and characteristic odor.

4 CONCLUSION

Ambient temperature greatly influences the activity of microorganisms in anaerobic digestion. The process is delayed under the influence of low temperatures, as it can promote a reduction in microbial activity. This treatment is optimized when hot periods occur, thus obtaining better removal efficiencies, mainly BOD and SV.

The pilot scale anaerobic biodigesters applied to this study proved to be efficient in the treatment of swine effluents. However, its efficiency depends on the temperature and the HRT adopted. The parameters most influenced by temperature were BOD, SV and COD.

Through the determination of parameters that interfere in the anaerobic biodigestion process, observed in this study, it is possible to promote a more efficient and sustainable management of swine manure, increasing efficiency in biogas production, reducing CO_2 emissions into the atmosphere, thus contributing to with the environment.

REFERENCES

ABPA, A. **Relatório Anual**, 2021. São Paulo: ABPA, 2021.

ALVES, R. G. C. M. **Tratamento e valorização de dejetos da suinocultura através de processo anaeróbio – operação e avaliação de diversos reatores em escala real.** 2007. 149 p. Tese (Doutorado em Engenharia Ambiental). Universidade Federal de Santa Catarina, Florianópolis, 2007.

APHA. 5-DAY BOD Test. In: STANDARD methods for the examination of water and wastewater. 22 nd ed. Washington: APHA; AWWA; WEF, 2012. p. 5-5 a 5-10 (Method 5210 B).

APHA. FIXED and Volatile Solids Ignited at 550ºC. In: STANDARD methods for the examination of water and wastewater. 22nd ed. Washington: APHA; AWWA; WEF. 2012. p. 2-67 (Method 2540 E).

APHA. OPEN Reflux method. In: STANDARD methods for the examination of water and wastewater. 22nd ed. Washington: APHA; AWWA; WEF, 2012. p. 5:17-18 (Method 5220 B).

ARAUJO, Michel Luan de**. Influência dos ácidos voláteis na geração de biogás.** Trabalho de Conclusão de Curso (Tecnologia em Processos Químicos) - Universidade Tecnológica Federal do Paraná, Toledo, 2022.

BASILE, Arianna *et al*. Revealing metabolic mechanisms of interaction in the anaerobic digestion microbiome by flux balance analysis. **Metabolic Engineering**, v. 62, p. 138-149, 2020.

CHERNICHARO, C. A. L. **Reatores anaeróbios**. Departamento de Engenharia Sanitária e Ambiental – DESA/UFMG. Vol.5. Belo Horizonte – MG, 1997. 246p.

DAL MAGO, A. **Avaliação de biodigestores com o uso de dejetos de suínos, em Braço do Norte e em Concórdia**. Florianópolis, SC: Universidade Federal de Santa Catarina, 2009.

de ARAUJO, G. J. F.; de Oliveira, S. V. W. B. Economic, energetic and environmental analysis of the utilization of swine manure in Brazil: Opportunities and challenges. **Energy Strategy Reviews**, v. 47, p. 101089, 2023.

DE OLIVEIRA, P. A. V. et al. Manual de manejo e utilização dos dejetos de suínos. 1993.

DO AMARAL, André Cestonaro et al. O processo de biodigestao. **Embrapa Suınos e Aves-Capıtulo em livro cientıfico (ALICE)**, p. 26, 2019.

SILVA, Hellen Luisa de Castro e et al. Lab-scale and economic analysis of biogas production from swine manure. **Renewable Energy**, v. 186, p. 350-365, 2022.

FERNANDES, Dangela Maria et al. Processo de biodigestão anaeróbia em uma granja de suínos The anaerobic digestion process on a pig farm. **Ambiência**, v. 10, n. 3, p. 741-754, 2014.

FREIRE, W. J. Aproveitamento de resíduos animais. Botucatu: UNESP, 1985.

IMA. Instituto do Meio Ambiente de Santa Catarina**. Instrução Normativa nº 11, de agosto de 2021 Suinocultura.** Florianópolis, 2021. p.52-93.

KONZEN, E. A. **Manejo e utilização de dejetos suínos.** Concórdia: EMBRAPA - CNPSA, 1983. 32p. (EMBRAPA - CNPSA. Circular Técnica, 6).

KUNZ, Airton; HIGARASHI, Martha Mayumi; DE OLIVEIRA, Paulo Armando. Tecnologias de manejo e tratamento de dejetos de suínos estudadas no Brasil. **Cadernos de Ciência & Tecnologia**, v. 22, n. 3, p. 651-665, 2005.

LEITE, Sibele Augusta F. et al. Swine meat production integrated with energy cogeneration: challenges and opportunities in using anaerobic biodigestion. **Bioscience Journal**, v. 39, n. e39087, p. 1981-3163, 2023.

MCAULIFFE, G. A. et al. Environmental trade-offs of pig production systems under varied operational efficiencies. **Journal of Cleaner Production**, v. 165, p. 1163-1173, 2017.

MORETTI, C. **Monitoramento da temperatura e eficiência de remoção de poluentes em um sistema de tratamento de efluentes de uma unidade produtora de leitões.** 2009. [S.I.]. Monografia (Especialização em Gestão Ambiental e de Recursos Hídricos) - Universidade Estadual do Oeste do Paraná, UNIOESTE, Cascavel, 2009.

OLIVEIRA, P. A. V.; HIGARASHI, M. M. **Geração e utilização do biogás em unidades de produção de suínos.** Concórdia: Embrapa Suínos e Aves, 2006, 41p. Programa Nacional do Meio Ambiente – PNMA II; Projeto de Controle da Degradação Ambiental Decorrente da Suinocultura em Santa Catarina.

ORRICO JÚNIOR, M. A. P. **Biodigestão anaeróbia e compostagem de dejetos de suínos, com e sem separação de sólidos**. 2007. 93 f. Dissertação (Mestrado em Zootecnia) - Universidade Estadual Paulista "Júlio de Mesquita Filho", UNESP, Jaboticabal, 2007.

PARANJPE, Archana; SAXENA, Seema; JAIN, Pankaj. Uma revisão sobre a melhoria do desempenho da digestão anaeróbica utilizando co-digestão de resíduos alimentares e lodo de esgoto. **Revista de Gestão Ambiental** , v. 338, pág. 117733, 2023.

PIEROTTI, S. M. **Avaliação da partida de reator anaeróbio de fluxo ascendente e manta de lodo (UASB, em escala real, sob condições hidráulicas desfavoráveis**. 2007. 141 p. Dissertação (Mestrado em Hidráulica e saneamento) – Escola de Engenharia de São Carlos-SP, 2007.

SANTOS, L. D. dos; MAYERLE, S. F.; ROCHA, J.; RODRIGUEZ, C. M. T. Pig production systems: biological, procedural, systemic and logistic approaches. **Revista Eletrônica em Gestão, Educação e Tecnologia Ambiental**, *[S. l.]*, v. 19, n. 2, p. 266–280, 2022. DOI: 10.5902/2236117015518. Disponível em: https://periodicos.ufsm.br/reget/article/view/15518. Acesso em: 12 sep. 2023.

SEGANFREDO, Gian Carlo et al. Viability of enterobacteria in swine manure storage units. **Pesquisa Agropecuária Brasileira**, v. 57, p. e02876, 2022.

SOUSA, I. P. et al. Study of internal and external temperatures and their influence on covered lagoon digester performance. **Biomass and Bioenergy**, v. 159, p. 106380, 2022.

SOUZA, Diego Bonfim de. Análise de metodologias para determinação do potencial de biogás proveniente da suinocultura no Brasil e seu aproveitamento energético. 2021. Tese de Doutorado. Universidade de São Paulo.

VAN HAANDEL, Adrianus C.; LETTINGA, Gatze. **Tratamento anaeróbio de esgotos: um manual para regiões de clima quente**. Editora Epgraf, Campina Grande, v. 240, 1994.

VIVAN, M.; KUNZ, A.; STOLBERG, J.; PERDOMO, C.; TECHIO, V. H. Eficiência da interação biodigestor e lagoas de estabilização na remoção de poluentes em dejetos de suínos. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v.14, n.3, p.320-325, 2010.

WANG, Shiwei et al. Influence of temperature on biogas production efficiency and microbial community in a two-phase anaerobic digestion system. **Water**, v. 11, n. 1, p. 133, 2019.

YAMADA, José Tadao et al. Use of factorial design with significant interaction and Tukey's test in agricultural and environmental experiments. **Revista de Gestão e Secretariado**, v. 14, n. 6, p. 9815-9828, 2023.

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How to quote this article

Piaia, F.; Rodrigues, C. R.; Pizzolatti, B. S.; Souza, V. Q.; Silva, R. F.; Rosa, C. O.; Passini, A. F. C.; Borba, W. F.; Silva, V. R.; Cadore, J. S. | 21 . Batch biodigesters efficiency in anaerobic biodigestion waste of swine. **Revista de Gestão, Educação e Tecnologia ambiental**. Santa Maria, v.27, e85240, 2023. DOI 10.5902/2236117085240. Disponível em: https://doi.org/10.5902/2236117085240. Acesso em: dia, mês abreviado, ano.