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Feasibility of Coagulation-Flocculation Followed by Mango Seed Filtration for Treatment of Swine Industry Effluent

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***Abstract*— *The effluent generated by pig farming has a high potential to cause pollution. However, correct disposal of pig farming effluent is not normal, due to the high cost of implementation and maintenance of conventional treatment systems. In this context, the present work sought to conduct a study of the feasibility of a two-step treatment: coagulation/flocculation system with subsequent filtration. In the coagulation/flocculation process, a polymer was used as a coagulant and the filtration process was carried out comparing two filters, one containing conventional sand and activated carbon and the other containing sand and activated carbon produced from mango seed. To analyse the viability of the treatment, pH, acidity, turbidity, total organic carbon, standard plate pathogen count and thermotolerant coliforms analyses were performed. The process proved to be efficient in removing the analysed parameters with emphasis on the removal of approximately 100% of the microbial load. An analysis of variance to compare the performance of activated carbon produced with conventional charcoal showed that the filters showed significant differences in all tests and, in most of the analyses performed, the activated carbon filter produced from mango seed presented a better performance. than conventional activated carbon.*

***Keywords*— coagulation-floculation; biopolymeraze; swine effluent.**

I. INTRODUCTION

According to the Brazilian Association of Pig Breeders (Associação Brasileira de Criadores Suínos), in 2015, Brazil had 1,720,255 heads, having produced 39,263,964 pigs for slaughter in 2015 (ASSOCIAÇÃO BRASILEIRA DE CRIADORES SUÍNOS, 2015). In 2018, Brazilian pig farming faced challenges related to the increase in grain prices combined with instability in exports and high production maintenance costs, which has led producers to work in an unfavourable financial situation (ASSOCIAÇÃO BRASILEIRA DE CRIADORES SUÍNOS, 2018).

Pig farming is considered a major cause of environmental pollution. Swine manure is made up of faeces, urine and water from the sanitation of the stalls, in addition to dust, hair, among other materials (KONZEN et al., 1997). In Brazil, the collection and treatment of sewage does not cover the rural area, leaving the producer responsible for the correct disposal of wastewater and solid waste from production management. However, due to the high investment costs required for the installation of treatment plants and the need for maintenance of treatment systems, the correct destination of such wate, for the most part, does not occur. Direct disposal (without proper treatment) causes soil contamination and increases the levels of metals such as sodium, zinc and copper, as well as high levels of pathogens and nitrate that can cause groundwater pollution and consequently cause reach the general population (MS, 2004).

Given the impacts caused by this activity and also the need to seek new sources of income for producers, the treatment and reuse of wastewater from the pig farming chain becomes a desirable option. Currently the techniques commonly used for the treatment of swine manure consist of physical, chemical and biological processes. New techniques to reduce the amount of waste generated and increase treatment efficiency are being studied and are in the research and development phase, such as the use of microalgae that increase the efficiency of biogas generation (Dias et al., 2016).

Coagulation is a process used in water and wastewater treatment that consists in destabilizing colloidal and suspended particles by the addition of a coagulant and has as characteristic the short time required for its realization (LIBANIO, 2010). In this process it is expected to remove suspended and dissolved organic matter, turbidity, toxic substances of organic and inorganic origin, substances that confer odour and microorganisms in general. It occurs in the quick mix unit and is of utmost importance to the performance of the rest of the treatment process. In the case of low coagulation efficiency, particles that are not removed will not be retained in the granular media of subsequent processes, e.g. direct filtration (BERNARDO; DANTAS, 2005). Thus, the choice of coagulant becomes an important factor and should be made in view of the type of effluent to be treated, the technology of treatment and the cost involved in purchasing the coagulant (BERNARDO et al., 2002). Currently, the coagulants most employed in treatment units are: aluminium sulphate, ferric chloride and ferric sulphate (KAWAMURA, 2000)

Aluminium sulphate is the most widely used coagulant in Brazil due to its low cost, high efficiency and the fact that it is produced in all regions of the country. However, the use of this coagulant generates two relevant problems regarding the maintenance of human health and the environment: (1) neurological diseases caused in humans associated with the presence of aluminium in the water and (2) the sludge generated by the treatment becomes impracticable for reuse (CARVALHO, 2008). Thus, natural coagulants present themselves as an alternative as, in addition to not containing potentially toxic substances, the generated sludge is biodegradable and/or can be reused.

Since the late 1950s in the USA, with the aim of reducing the use of chemical coagulants and optimizing the coagulation process, natural or synthetic polymers have been employed as coagulation aids in water treatment processes (LIBANIO, 2010). The use of natural or synthetic polymers has been efficient in wastewater treatment, for example in the treatment of tannery effluent (Gomes et al., 2016). Natural and synthetic polymers can be classified as anionic (negatively ionized sites), cationic (positively ionized sites), or ampholytic (with negatively and positively ionized sites) (BERNARDO; DANTAS, 2005). However, studies investigating the use of polymers in the treatment of swine effluents are scarce (STEINMETZ et al. 2009), which justifies an investigation in this context, as it may represent an environmentally friendly, simple to use and low-cost alternative.

II. MATERIAL AND METHODS

2.1. ACTIVATED CARBON PRODUCTION

Mango seeds from the species Palmer, were purchased in the city of Uberaba – MG. The activated carbon production was performed employing the following steps (TELES; FURTADO, 2016): (1) washing and removal of pulp from the seed, (2) drying in the sun for 6 h, (3) drying in oven at 50ºC for 6 h, (4) chemical activation with 10 g / L NaOH for 24 h, (5) oven drying at 50ºC for 6 h, (6) carbonization in a mufla oven at 400ºC for 1 h. After cooling the carbon was washed several times in running water to remove excess activating agent and dried for 6 h at 50ºC.

2.2. FILTER CONSTRUCTION

For the construction of the filter, 500 ml PET bottles of water were collected. As the filter material, 200g of sand was mixed with 40g of activated carbon (standard or from mango seeds). The amount of sand was kept constant for standardization of the tests. For the complete construction of the filter, a small amount of cotton was placed at the exit point, so that no particle drag occurred. To support this configuration, a screen made of cloth with openings large enough so that it did not interfere with filtration was tied to its output point. The filters using standard carbon or from mango seeds were constructed in triplicate.

2.3. EFFLUENT SAMPLING

The effluent was supplied by the companys Fertagro and Bioideias, from a swine farm localized in the City of Uberaba, Minas Gerais State, Brazil. The effluent received only one pre-treatment before being collected - with grating to remove coarse solids. A sample of the effluent is illustrated by Figure 1. In all, 6 L of raw effluent were used.

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Fig.1: Visual characteristic of the swine effluent sample used in the experiments.

2.4. BENCH TEST

The polymer used is known as Biopolimeraze (The new product developed by the company) and was supplied by the company Fertagro and diluted with water at a ratio of 1:10. In order to investigate which polymer concentration would be used in the coagulation step, initial bench tests were performed using 20 mL of raw effluent. Manufacturer data recommends a concentration of 20 mL / L of polymer for domestic sewage treatment. As the domestic effluent presents lower organic matter, turbidity and microbiological loads than the pig effluent, the concentrations chosen for the bench tests were higher than recommended (ARAÚJO et al., 2012; AISSE et al., 2000). After the polymer was added to the raw effluent, the mixture was stirred for 10 s and then decanted for 30 min. Ratios (mL of polymer to raw effluent) of 30, 40, 50, 60, 70, 100, 125, 150 mL were tested.

2.5. JAR-TEST

For the jar-test assays (Milan, JT303M – 3 jars), 2 L of raw effluent were added to each jar and placed under agitation (100 rpm) for homogenization of the mixture. Subsequently, the fast mix was simulated by simultaneous addition of the coagulant to the 3 jars, mixing for 10 s and then resting for 30 min so that all the solid was decanted in the jar. The supernatant material was subsequently removed.

2.6. FILTRATION

The supernatant from the coagulation was divided into two 500 ml conical flasks for each jar and then filtered under gravity through the previously constructed filters.

2.7. PHYSICOCHEMICAL ANALYSIS

In order to investigate the behaviour and the removal efficiency of the treatment, physical and chemical analyses of the effluent and filtrates were performed. The following analyses were performed in triplicate:

- Total Organic Carbon (TOC), Inorganic Carbon (IC) and Total Carbon (TC) analyses were using a total organic carbon analyser (SHIMADZU). These parameters refer to dissolved fractions of carbonic species smaller than 0.45 µm.
- pH measurement was performed using a digital pHmeter (LAB 1000 model mPA210).
- Turbidity - Turbidity was measured using turbidimeter (LAB 1000) calibrated with standard solutions.
- Acidity by titration was performed with 0.01 N NaOH and 1% phenolphthalein as indicator. The degree of acidity was obtained as mg CaCO3 / L.

2.8. PHYSICOCHEMICAL ANALYSIS OF THE SLUDGE

The sludge generated in the treatment was dried in an oven and in order to investigate its potential use as an organomineral fertilizer. Total nitrogen, phosphorus, potassium and total organic carbon analyses were performed. The analyses were performed by the laboratory LABFERT, located in the city of Uberaba - MG.

2.9. MICROBIOLOGICAL ANALYSIS

Microbial analysis was performed in order to investigate the initial microbiological charge and subsequent removal of the from the raw and filtrate effluent.

2.10. EXPERIMENTAL DESIGN

The data obtained in the physicochemical analyses of the raw and filtered effluent passed the normality tests, as verified by the Kolgorov-Smirnov test with Lilliefors correction. The ANOVA should be performed to verify and compare the performance of the activated carbon filter produced from the mango kernel with the conventional activated carbon filter. For the null hypothesis rejected, the data passed the Tukey test to verify the significance of the factors.

All tests were performed with a 95% confidence level with the aid of Excel®. To prevent undesirable and unknown factors from interfering with the response of the studied effects, the analyses were performed in triplicate.

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III. RESULTS AND DISCUSSION

For the production of activated carbon, preliminary tests were carried out in order to investigate the behaviour of the material when using a Mufla furnace. The mango seeds were heated at 400ºC for 3 h, as performed by Teles and Furtado (2016). After 3 h the material was removed, and it was found that it had been completely converted into ashes. This result was not expected. Both Teles and Furtado (2016) and Kwaghger and Adejoh (2012) suggest that an adjustment in the amount of material used and a shorter time in the carbonization stage would be more favourable for activated carbon production. Thus, for the subsequent tests, ~120 g (six to eight seeds) of material were used, divided into two crucibles for a carbonization time of 1 h. The result of the production of activated carbon from the mango seed is shown in Figure 2. In total, approximately 150 g of activated carbon were produced. Figure 3 represents an enlarged image of the activated carbon produced and it is possible to observe that the result was satisfactory as the material is visually porous.

Fig.2: Image of activated carbon from mango seed.

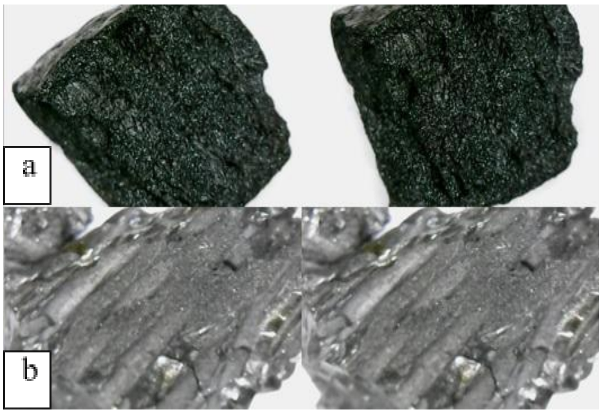

Fig.3: Enlarged images of activated carbon produced from (a) mango seed and (b) conventional activated carbon. Magnification: 40 x.

The results of the bench tests are illustrated in Figure 4. It can be seen that in the higher concentrations of the polymer the supernatant became visibly clearer. As a result, the concentrations chosen in the subsequent tests were 100, 125 and 150 mL / L, which represent respectively, 10, 12.5 and 15 g of the polymer.

Subsequently, coagulation tests were performed under agitation of 100 rpm for 10 s for (rapid mixing step) and a decantation time of 30 min, as performed in the bench tests. It was possible to observe a clear difference, compared to small-scale tests, which is possibly due to errors at the time of polymer dosage. In the preliminary investigation, only 20 mL of effluent was used, so the amount of polymer added was small and the dosage was performed by means of automatic micropipettes. For the jar test 2 L were used. Thus, a large amount of polymer was used, and its dosage was performed using 500 mL beakers. When added to the jars, it was observed that a small amount of material adhered to the beaker surface, causing losses and decreasing the added concentration. Another factor that may have influenced the efficiency of the test is the speed of rotation of the rapid mixing step. After consulting the polymer manufacturer, it was found that the speed of rotation is an important factor for the efficiency of the process. In this sense, a deeper investigation regarding the rotation speed for jar tests is necessary.

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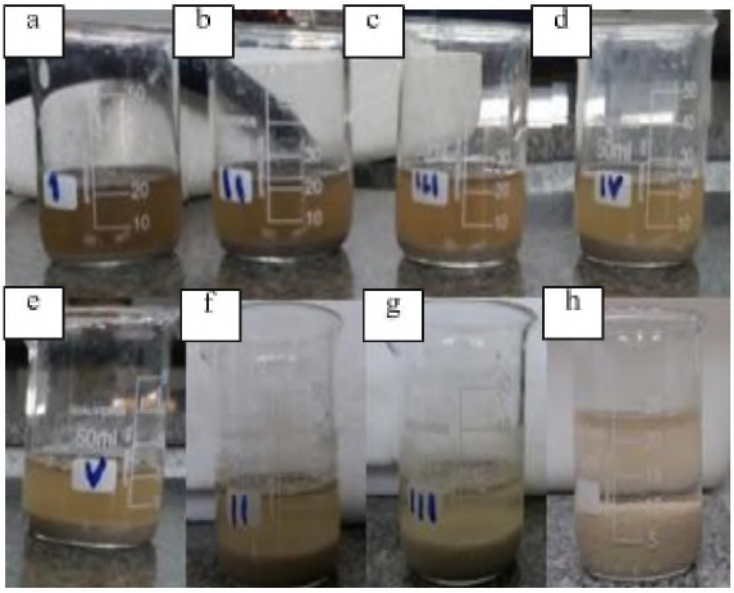

Fig.4: Bench tests of polymer with ratios (mL of polymer to raw effluent) of: a) 30 mL / L; c) 50 mL/L; e) 70 mL/L; g) 125 mL/L; b) 40 mL/L; d) 60 mL/L; f) 100 mL/L; h) 150 mL/L.

Following the jar-test, the supernatant liquids were collected and transferred to flasks and subjected to filtration. The decanted solid was collected and dried in an oven. Once dry, the solid is an odourless, fine powder that can be studied for application as a fertilizer. The results of the physical-chemical and microbiological analyses of the raw effluent (RE) and the filtrates, identified as M for the activated carbon filter of the mango seed and C for the conventional activated carbon filter are given in Table 1. Test 1 represents the concentration of 100 mL/L, Test 2, 125 mL/L and Test 3, 150 mL/L.

Table 1: Results of physico-chemical and microbiological analyzes of the effluent and filtrates with mango seed active carbon and traditional active carbon.

	Filter	pH	Turbidity [NTU]	Acidity [mg $CaCO_3$/L]	CE [mS/cm]	CI [mg/L]	TOC [mg/L]	CT [mg/L]	MPC	Termotolerant coliform (NMP)
RW	-	8,19 ± 0,04	1128 ± 29,71	441,66 ± 2,35	8,28 ± 0,05	633,85 ± 3,85	204,85 ± 6,95	838,70 ± 10,80	1.040.000	>23
Test 1	1 M	12,23 ± 0,03	8,06 ± 0,19	-	3,94 ± 0,14	127,10 ± 0,40	102,20 ± 2,60	229,30 ± 3,00	160	<1,1
	1 C	12,23 ± 0,01	13,63 ± 3,16	-	4,14 ± 0,11	129,65 ± 2,52	148,60 ± 35,90	278,25 ± 35,15	900	<1,1
Test 2	2 M	12,29 ± 0,03	3,00 ± 0,38	-	6,24 ± 0,03	96,93 ± 1,13	97,66 ± 3,43	194,60 ± 2,30	150	<1,1
	2 C	12,32 ± 0,01	2,80 ± 0,30	-	6,13 ± 0,18	93,7 ± 0,8	108,88 ± 1,22	202,60 ± 0,42	160	<1,1
Test 3	3 M	12,30 ± 0,01	3,63 ± 0,37	-	6,21 ± 0,30	116,85 ± 1,05	100,95 ± 3,65	217,80 ± 2,60	140	<1,1
	3 C	12,31 ± 0,02	5,50 ± 0,43	-	5,13 ± 0,24	147,85 ± 0,55	114,15 ± 2,15	262,00 ± 1,60	90	<1,1

From the data it can be seen that the raw effluent (RW) presents high levels of turbidity, acidity, pathogens and thermotolerant coliforms. The carbon load represents the dissolved fractions of <0.45 µm and it is observed that the predominant carbon species are inorganic (IC), and the Total Organic Carbon (TOC), represents 24.42% of the total carbon (TC).

According to Bernardo and Dantas (2005), acidity can be understood as the capacity for base neutralization. According to Libânio (2010), for pH values between 4.5 and 8.2 the acidity in solutions comes from carbon dioxide. In Table 1, the raw effluent (RW) has an average acidity of 441.6 mg / L of $CaCO_3$. However, for the filtrates, at the time the indicator was added, the solution turned pink instantly with zero acidity. Figure 5 shows the efficiency in removal of inorganic carbon (IC). According to Pavanelli (2001), inorganic carbonic species from carbon dioxide in solution are based on the carbonic acid balance system as a function of pH. The total removal of acidity is related to the

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high removal of inorganic carbon in the treatment. Test 2 with filter C, obtained greater efficiency reaching 85.22% of removal, however in Test 3, filter M (put the value) obtained a better performance compared to filter C.

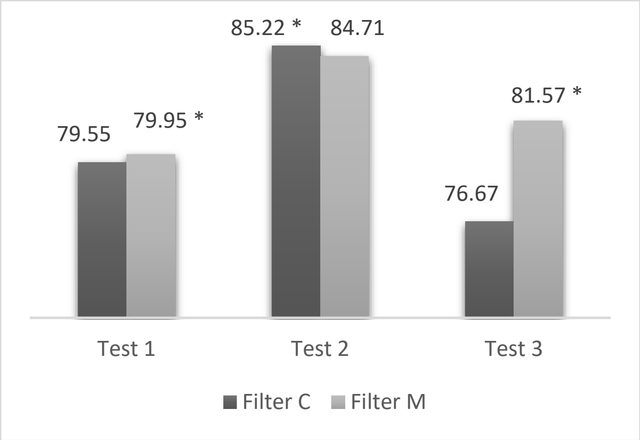

Fig.5: Result of the efficiency of removal of inorganic carbon in the three tests (%) performed: Test 1 (100 mL / L of polymer); Test 2 (125 mL / L of polymer) and Test 3 (150 mL / L of polymer).

Figure 6 shows the results of total organic carbon (TOC) removal. It is possible to observe that in Test 1 the mango seed filter (M) presented the best performance (50.1 %) whilst the filter with commercial activated carbon (C) achieved 27.31%. In the other tests the M filter maintained the best performance, however in Tests 2 and 3 the filter C obtained a higher efficiency than in Test 1. When comparing the efficiency of IC removal with TOC, it is possible to observe a better performance in IC removal. According to Matilainen, Vieno and Tuhkanen (2006), who studied the performance of activated carbon filters in the removal of organic matter, filters of this nature generally perform better in the removal of small and low molecular weight organic molecules. One of the factors that can influence greater efficiency in TOC removal would be the spraying of activated carbon, which would increase the surface of contact with the fluid, which may influence the physical and chemical interactions of the filtration process.

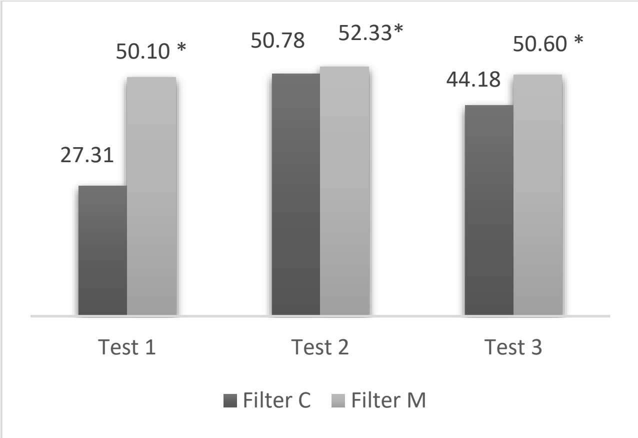

Fig.6: Result of the efficiency of TOC removal in the three tests (%) performed: Test 1 (100 mL / L of polymer); Test 2 (125 mL / L of polymer) and Test 3 (150 mL / L of polymer)

Figure 7 presents the total carbon (TC) removal efficiency. In general, carbon removal was greater for filter M than filter C, with Test 2 in filter M having the highest performance, reaching 76.8% removal and in Test 1, filter C had the worst performance (66.82%).

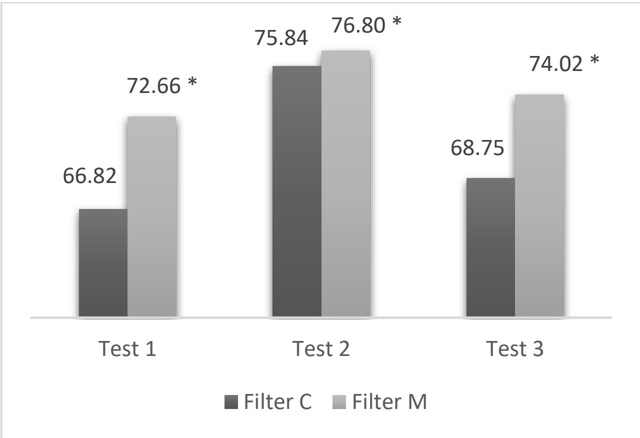

Fig.7: Result of total carbon removal efficiency in the three tests (%) performed: Test 1 100 mL / L, Test 2 125 mL / L and Test 3 150 mL / L of polymer.

Figure 8 shows the turbidity removal efficiency for the tests. The treatment proved to be very efficient in removing turbidity. In just two treatment stages, removal levels above 99% were achieved. Test 2 and proved to be the most efficient in removing turbidity, reaching 99.75% and 99.73%. for filter C and filter M, respectively. In Test 1, filter C presented the lowest performance at 98.79%. According to Libânio (2010), turbidity consists predominantly of suspended and colloidal particles, and corresponds to particulate organic and inorganic matter, microorganisms, clay fragments, etc. Thus, it can be said that the treatment performed proved to be efficient both in the removal of dissolved inorganic and particulate matter.

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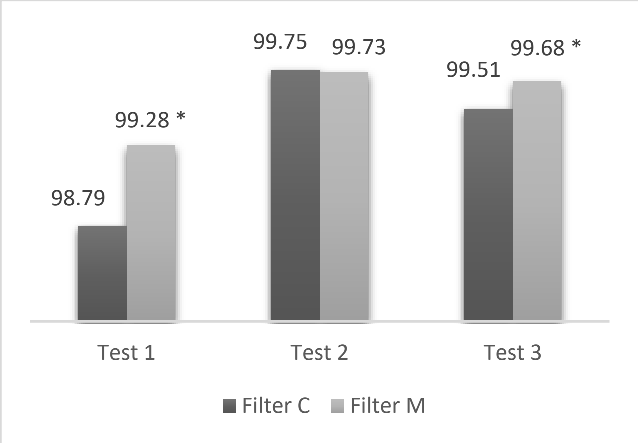

Fig.8: Result of total turbidity removal efficiency in the three tests (%) performed: test 1 100 mL / L, test 2 125 mL / L and test 3 150 mL / L of polymer.

Table 1 presents the results of the microbiological analyzes of the raw effluent and the filtrates. After the analysis of the raw effluent, as expected, a standard microorganism plate count (MPC) value of 106 microorganisms was found. A thermotolerant coliform count, which corresponds to the most probable number (MPN), of 23 was observed. In analysis of the filtrates, it was found that the treatment proved to be efficient in disinfecting the effluent, and Test 3 with filter C had the better performance in removing MPC, showing an efficiency of 99.99%, eliminating approximately 100% of the microbial load. When analyzing the results of the filters, we can see that in all tests the results were close to 100% efficiency. In all tests, the removal of thermotolerant coliforms was 100%, thus raising the hypothesis that the polymer used in the coagulation / flocculation step had removed the microbiological load from the effluent. Therefore, a new test, as for the bench tests, was carried out in order to investigate the action of the polymer and it was found that, in fact, it was responsible for the microbiological removal.

From Table 1, it can be seen that the pH values of the filtrates were between 12.23 and 12,32 (basic). A basic pH can influence the inactivation of microorganisms during treatment (FRANCO; LANDGRAF, 2008). The solid material formed by the decantation of the flakes, was taken to the oven for drying, and the result was a fine, odorless powder that is easy to dry and handle, different to sludge generated by conventional wastewater treatment. Table 2 shows the results of the physio-chemical analyzes performed on the generated solid material. It can be observed that the material has an index of 3% of TOC, which is expected due to the nature of the effluent and the coagulant used, for nitrogen, phosphorus and potassium, the indexes found were 1%, 0.8% and 0.12%, respectively, which reforces the potential for use as an organomineral fertilizer, probably combined with another fertilizer.

Table 2 – Result of the physico-chemical analysis of the sludge produced.

Parameter	Result (g / 100g)
Total Nitrogen	1.0
Total Phosphourous	0.8
Potassium	0.12
Total Organic Carbon	3.0

In order to analyze whether there are differences in the performance of the M and C filters, double-factor ANOVA with repetition was performed, with $\alpha = 0.05$. For data validation, a normality test was performed, in which all the collected data fell within normality, with a 95% significance level. The ANOVA results are presented in Table 3, and the statistical tests were performed for the turbidity data, TC, IC and TOC. Analyzing the p value for the samples, that is, comparing the filters C and M, and for the columns, comparing Tests 1, 2 and 3 it can be said that there are significant differences in the mean of the values, since the p value is less than α for the data. Thus, the Tukey test was performed (Table 4) to verify at which levels there was a significant difference. For the turbidity and TOC analysis, only Test 1 showed a significant difference between the filters, since the mean difference module is greater than the calculated minimum significant difference (MSD). Analyzing the results for TC it can observed that in Tests 1 and 3 the filters displayed significant differences for the values found. For IC, only test 3 showed a significant difference between the filters.

Table 3 – p-values for ANOVA using a double repeat factor.

Análise	Fonte de variação	Valor - *p*
Turbidity	Sample	$1,12x10^{-2}$
	Columns	$8,81x10^{-6}$
CT	Sample	$3,06x10^{-5}$
	Columns	$1,43x10^{-5}$
CI	Sample	8,48x10-^{5}
	Columns	$2,51x10^{-7}$
COT	Sample	$3,5x10^{-3}$
	Columns	$8,35x10^{-3}$

Table 4 – Tukey test values

Analysis	SMD	Test	Average difference (modulus)
Turbidity	0.263	1	0.497
		2	0.017
		3	0.166
TC	1.370	1	5.843
		2	0.955
		3	5.269
IC	0.648	1	0.399
		2	0.512
		3	4.891
TOC	8.400	1	22.789
		2	1.546
		3	6.426

Observing the physical-chemical and microbiological results of the treatment process applied, it can be said that it presents itself as viable for the treatment of swine effluents. This is true being that a treatment system has several stages, requiring periodic maintenance and high costs (ARAÚJO et al., 2012). On the contrary, the treatment performed consisted of two simple and low-cost steps, achieving satisfactory results for different factors. During the experiments it was possible to observe that the coagulation-flocculation stage had a greater influence on treatment. It is believed that this is due to two factors: 1) because the polymer used has positive and negative ionizable sites, the neutralization of colloidal, suspended and dissolved particles present in the effluent is favored; 2) due to the fact that according to Bernardo and Dantas (2005), descending filters with fast action have depth action, where the particles are retained along the filter medium, thus a higher filter could indicate a greater efficiency in the treatment. In this sense, the polymer presents itself as a potential primary coagulant for the treatment of different effluents, since polymers are usually used and studied as auxiliaries in the coagulation process (RODRIGUES FILHO et al., 2013; LIMA, 2007).

As observed by Teles and Furtado (2016), the activated charcoal produced from the mango seed can be used in water treatment. However, for the treatment of swine effluent, it did not obtain satisfactory results. In view of this, a broader investigation regarding the type of filter and filter medium to be used in this treatment is necessary.

IV. CONCLUSION

The present work aimed to evaluate the viability of a swine effluent treatment system, which consisted of coagulation with the use of a polymer as a coagulant, followed by filtration in two filters, in order to compare the performance of activated carbon produced from mango seed with conventional activated carbon, found on the market. The M filter had better performance than the C filter, except in two tests, in that sense the activated carbon from the mango seed proved to be more efficient than the conventional activated carbon.

The treatment process in general proved to be viable, however the performance of the coagulation step was below expectations when compared to the results of the bench tests, although the polymer was shown as an alternative to the use of chemical coagulants, once that in just one step, is able to remove odor, particulate and dissolved material, inactivate microorganisms, in addition to producing a by-product that can be reused. Thus, an investigation into the effect of the rotation speed and concentration of the polymer used is necessary.

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