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RESEARCH ARTICLE

BACTERIOLOGICAL CHARACTERISTICS AND STABILIZATION OF SEWAGE SLUDGE SUBJECTED TO DIFFERENT HYGIENIZATION PROCESSES

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ABSTRACT

This study aimed to evaluate the efficiency of solar radiation, combined with chemical treatment in acid and alkaline media during different hygienization periods given the total content of volatile solids, total solids, temperature, pH and total coliforms in sewage sludge. The experimental design process used was randomized blocks in a 5x3 +1 factorial scheme, with four replications, with plot factor being made up of disinfectant products (260 mg L^{-1} peracetic acid, 2400 mg L^{-1} Quaternary Ammonium Compounds, lime equivalent to 30% of the dry mass of the sewage sludge, 2500 mg L-1 sodium hypochlorite and pure sludge) and subplot factor being treatment period (T_1= 7 days, T_2= 14 days and T_3= 21 days), plus an additional treatment made up of pure sludge at zero time. Hydrated lime at 30 dag kg^{-1} has reduced levels of total coliforms to acceptable limits by environmental standard, has raised total solid content, reduced volatile solid content and lowered foul odor emissions. Solar radiation itself was not able to reduce the amount of total coliforms to an acceptable standard required by Brazilian environmental legislation. Hydrated lime in the ratio of 30% dag kg^{-1} by weight of dry mass can be used as a way to disenfect sweage sludge, concerning bacteriological content and stabilization. The other disinfectant products did not perform the same efficiency on reducing total coliforms or volatile organic compounds.

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INTRODUCTION

Sewage sludge is a product of wastewater treatment system and contains high levels of organic matter in addition to macro and micronutrients which are essential to plants (Quintana *et al*., 2011). According to Pires *et al*. (2008), the reuse of wastes in agriculture is the most interesting option from social, economic and envinronmental point of view. However, the solely disposal of sewage sludge in landfill, accepted nowadays by organs which integrates National Environment System (SISNAMA) in Brazil, does not eliminate its potential to cause pathologies or environmental contamination, more than postpones an environmental problem to a near future. To Andrade *et al*. (2006) biosolid agricultural recycling is an alternative to minimize the problem of waste sludge final disposal, as well to prevent possible hostile effects to environment, taking the preservation of natural resources into account and seeeking, at the same time, agronomic benefits. Nascimento *et al*. (2014) and Samaras *et al*. (2007) reported that use of sewage sludge on agricultural land is a matter of concern due to the larger concentrations of heavy metals, pathogenic agents and a handful of synthetic organic compounds. The five groups of pathogenic microorganisms which may be present in sewage sludge are: helminths, protozoa, fungi, viruses and bacteria (Costa and Costa, 2011). According to Jordão and Pessôa (2005), the presence of pathogenic agents together with microorganisms in sewage sludge is a direct reflection of the health profile from people who contribute with wastewater system. To the bacterial characterization, resolution 375/2006 from CONAMA (National Council of the Environment) lists bacteria as belonging to the group of total coliforms, with the group of bacteria being used as bacteriological indicator in sewage sludge agricultural reuse (Brazil, 2006).

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The raw sewage sludge, that is, untreated, is rich in pathogenic microorganisms easily putrescible, thus, releases foul-smelling odors. The biodegradable fraction from organic matter in the sludge, also known as total volatile solids, must be stabilised with the purpose of reducing the risk of putrefaction and pathogenic concentration. Stabilization is the process by which sewage sludge meant for agriculture ceases to present potential to generate odors and vectors attractiveness, even when humidified again (Brasil, 2006). Various ways are applied to warrant the hygienization and the framework for legal limits of resolution 375/2006 from CONAMA, such as: composting, solarization, vermicomposting, liming, chemical treatment with acetic acid, peracetic acid, sodium hypochlorite and quaternary ammonium salts (Nascimento et al., 2014; Barros et al., 2011; Barros et al., 2006; Ruan et al., 2014 e Samaras et al., 2007). To Farzadkia; Bazrafshan (2014) sludge stabilization with hydrated lime is accomplished when sludge's pH raises to above 12.0. According to Samaras *et al.* (2007), liming to stabilize sewage sludge is broadly used in many countries, but its usage depends on avaiability, costs and the period needed to the stabilization of sludge. In this sense, other kind of materials to hygienization of sweage sludge can be considered. To Sypula *et al.* (2013) one effective method to improve hygienic state of sweage sludge is solar drying it, for pathogenic bacteria are extremely sensitive to moisture loss. The same way, solar radiation, specifically ultraviolet radiation, is well known for its bactericidal effect (Pinto *et al*., 2001). However, given brazilian conditions, there is few information on solar radiation real's capacity, by itself or combined with other methods, to eliminate pathogenic microorganisms in sewage sludge. This work's objective was to evaluate the efficiency of solar radiation, combined with chemical treatment in acid and alkaline media during different hygienization periods given the total content of volatile solids, total solids, temperature, pH and total coliforms in sewage sludge

MATERIALS AND METHODS

The experiment was performed at the Glória Experimental Farm of the Federal University of Uberlândia (UFU), in Uberlândia, MG, from 7 August to 27 August, 2013. The local climate is classified as Aw, according to Koppen classification, with a dry season (from may to september) and a wet one (from october to april). The sewage sludge used was extracted from an anaerobic reactor UASB type (Upflow Anaerobic Sewage Sludge Blanket) belonging to Uberabinha Sewage Treatment Plant of DMAE - Department of Water and Waste water, located in Uberlândia, MG. The sludge is from domestic sources after passing through a dewatering process by adding cationic polymers (FeCl3) and centrifuging to a moisture level of 71.21 and 28.79% dry matter. The experimental design was a randomized block in a factorial 5×3+1, with four replications of factor plots consisting of disinfectant products (260 mg L-1 peracetic acid, 2400 mg L-1 quaternary ammonium compounds, hydrated lime equivalent to 30% of the dry mass of the sewage sludge, 2500 mg L-1 sodium hypochlorite, and pure sludge) and subplot factor being treatment period (T_1= 7 days, T_2= 14 days and T_3= 21 days), plus an additional treatment made up of pure sludge at zero time (initial quality), in a total of 64 subplots (Table 01).

Table 1. Treatments used in the sewage sludge hygienization process and their concentrations at 7, 14 and 21 days

Treatments	Chemical concentration
Sludge + peracetic acid	260 mg L^{-1}
Sludge + Quaternary compounds of amonium[1]	2400 mg L^{-1}
Sludge + Hydrated lime	30% of sludge dry matter
Sludge + Sodium hypochlorite	2500 mg L^{-1}
Pure sludge without chemical	-

1/ Dicetyl ammonium chloride, alkyl amido propyl chloride, dimethylbenzyl ammonium, alcohol and water.

The experiment plots consisted of metal boxes of 0.30 × 0.23 × 1.0 meters on pedestals in order to eliminate as much interference from the ground such as humidity and temperature as possible. Each chemical treatment with peracetic acid, sodium hypochlorite, quaternary ammonium compounds and hydrated lime, also pure sludge, was blended in a mixer for three minutes. In each metal box, corresponding to one experimental unit (plot), were put 30 kg of the mixture, containing sewage sludge and hygienization material, including treatment related only to pure sludge, in a total of 0.1 m^3 m^{-2} sludge per box. Instruments to measure temperature were implanted in each box at a depth of 5,0 cm into the sludge mass and at 40 cm from the end of the receptacle. Data were stored in a datalogger, model CR 1000 (Campbell Scientific®), calibrated to record temperatures at 30 minutes intervals daily throughout the experimental period. Into each block, consisting of five boxes, a 5.0 mm transparent glass was applied in order to enable a greenhouse effect inside each unit and to avoid moisture, such as rainfall, from external environment. A ribbon was placed between the glass and the boxes to prevent the entrance of air and moisture. An autoclaved spatula was used to collect each sample. Within each plot, four sub-samples were collected at different depths of the sludge, from surface to the bottom of the box. The analysis of total coliforms, total volatile solids, humidity (105°C) and pH were carried out in the Environmental Microbiology Laboratory of the Federal University of Uberlândia. To the analysis of total coliforms it was used the technique of multiple pipes, recommended by the United States Environmental Protection Agency for sludge analysis (USEPA, 2006). Concerning the volatile solids (VS), moisture, total solids and pH, the methodology used was the one recommended by EMBRAPA (Brazilian Agricultural Research Corporation) (2009), Table 02.

Table 2. Physical and bacteriological characteristics of sweage sludge[1]

Microbiological Analysis	Results	Units	Methodology
Total Coliforms	3.53×10^8	MPN g^{-1} ST	USEPA, 2006
Total Volatile Solids (VS)	57.39	dag kg^{-1}	EMBRAPA, 2009
Humidity at 105° C	71.21	dag kg^{-1}	EMBRAPA, 2009
Total Solids (ST) at 105°C	28.79	dag kg^{-1}	EMBRAPA, 2009
pH in $CaCl_2$ 0,01 mol L^{-1}	8.62	-	EMBRAPA, 2009

MPN: Most Probable Number. 1/ Analysis perfomed at soil analysis laboratory of the Institute of Agricultural Sciences - Federal University of Uberlândia.

Analyses of the data variances were developed using the SISVAR statistical program (Ferreira, 2008) and ASSISTAT (Smith, 2002) and when findings were significant, the averages for that unit were compared by the Scott and Knott test (1974) using a 5% significance level. In order to test the time factor, the Tukey test was applied, also using a 5% significance level.

The averages were still compared to the additional treatment by the Dunnet test, applying a 0.05 level of significance.

RESULTS AND DISCUSSION

The average concentration of total coliforms in the sewage sludge before cleaning was 3.53 x 10^8 MPN g^{-1} ST, which is within the range related by Bonini *et al*., (2010) (Table 3).

Table 3. Total coliforms in (MPN) g^{-1} TS, due to their submission to different processes of treatment and evaluation time

	Incubation period (days)			
Treatment	0	7	14	21
Control	3,53 x 10^8*			
Peracetic Acid		*1,04 x 10^6 Bb	*1,28 x 10^5 Bb	*8,50 x 10^3 Ab
Quaternary ammonium		*5,01 x 10^6 Bc	*6,16 x 10^5 Bb	*2,04 x 10^4 Ab
Hydrated Lime		*0,71 Aa	*0,23 Aa	*0,23 Aa
Sodium hypochlorite		*3,54 x 10^5 Bb	*3,23 x 10^5 Bb	*1,86 x 10^4 Ab
Pure Sludge		*4,4 x 10^6 Bc	*3,31 x 10^6 Bc	*7,24 x 10^5 Ab

Means followed by the same lower case letters in the (Scott-Knott) column and the same capital letters in the (Tukey) column did not differ at the 5% significance level. * Significant at 5% by the Dunnett test.

Hydrated lime (Ca $(OH)_2$), when added to sewage sludge in a proportion of 30 dag kg^{-1} of its dry mass, raised the pH to higher than 12.0 throughout the whole 21 days period. In this condition, ions from NH_4^+ are deprotonated producing NH_3 (ammonia) which acts into the process of elimination of total coliforms. The reduction in the concentration of coliforms from 3.53 x 10^8 MPN g^{-1} of Total Solids to 0.71 MPN g^{-1} Total Solids has taken place seven days after the addition into the sewage sludge (Table 3 and 4). Matos *et al.* (2012) reveal that liming process raises pH to values close to 12 and eliminates most of the pathogens present in the residue. Arthurson (2008) mentions that maintaining pH above 12.00 for 2 hours is enough to eliminate bacteria from coliforms group in the sewage sludge mainly due to elevation of pH and production of NH_3. The concentration of total coliforms in sewage sludge on 14 and on 21 days was unchaged with values of 0.23 MPN g^{-1} of Total Solids, respectively (Table 3). No significant change was observed in the treatment with hydrated lime on the reduction of total coliforms between periods of seven (07), fourteen (14) and twenty one (21) days. After a great reduction in the average concentration of total coliforms in the limed sludge during seven days, no regrowth was observed at 14 and 21 days. In the external environment, microorganisms require na intermediate host to multiply. Results indicate that a severe reduction on the concentration of total coliforms may have happened before 7 days of treatment, suggesting the conduction of new studies with shorter periods of treatment. Quaternary ammonium salts produced no efficient reduction in total coliforms. The average concentration of total coliforms on 21 days after mixing quaternary ammonium salts to sewage sludge was 2.4 x 10^4 MPN g^{-1} TS. Brazilian environmental legislation mentions that the higher concentration of bacteria belonging to the group of total coliforms in sweage sludge must be less than 10^3 MPN g^{-1} TS, when the residue is for agricultural use. The low efficiency of quaternary ammonium salts on reducing the concentration of total coliforms in sewage sludge results of the high amount of organic matter and the low concentration of moisture of the residue, factors that inhibit the contact of the hygienization agent with microorganisms into the sludge. On the other hand, bacteria from total coliforms group are gram-negative and quaternary ammonium salts present low efficiency to eliminate them. According to Lengert (2008) quaternary ammonium compounds are highly effective against gram-positive bacteria but do not show the same effect against the gram-negative ones. To Cony e Zocche (2004) quaternary ammonium compounds' effects are restrained in the presence of organic matter and in areas with soap and anionic detergent traces. Kuana (2009) mentions that the performance of quaternary ammonium compounds is greatly reduced by hard water, fibrous materials, soap and anionic residues, as well as organic matter. Pure sewage sludge with no addition of acid or alkaline chemical products showed a decrease on the levels of total coliforms during the 7, 14 and 21 days of evaluation. Regardless of the means used for hygienization, a drop on the concentration of total coliforms on 21 days after the beginning of the experiment was clear to observe. The reduction on levels of total coliforms is due to solar radiation present in the evaluated treatments, which has led to moisture loss and as enhanced bactericidal effect. Sewage sludge treated with sodium hypochlorite, at the concentration of 2.500 mg L^{-1}, presented an average concentration of total coliforms of 1.86 x 10^4 MNP g^{-1} TS after 21 days of the mixture. The amount of total coliforms still present in the sludge homogenized with sodium hypochlorite after the 21 days's cycle was above the standard framed by resolution n.° 375/2006 from CONAMA. The low perfomance of chlorine on the elimination of total coliforms in sewage sludge is mostly due to the eminent amount of solids into the mud, the great amount of organic matter, low humidity level and the initial pH of alkaline sludge (Table 3). To Lengert (2008), chlorine disinfectant react rapidly with organic matter, including blood, feces and tissues, which sharply decreases disinfection effects. Aisse *et al.* (2003) mention that the high amount of solids in the residue can protect microorganisms from the disinfection effects. To Kuana (2009), chlorine's bactericidal effect is assured into strips of neutral and acid pH (from 5 to 7). At the present case, pure sewage sludge presented alkaline pH (8.65). Sewage sludge treated with peracetic acid presented a 8.50 x 10^3 MPN g^{-1} TS average concentration of total coliforms on 21 days after the beginning of the experiment. Therefore, it did not reduce the level of total coliforms to the limits established by resolution n° 375/2006 from CONAMA. Peracetic acid is an oxidizing agent and works denaturing microorganisms' proteins. According to Fraser *et al* (1984), the time acid is in contact with the sludge is too short and decomposition products are biodegradable. In this specific study, it was not efficient to eliminate total coliforms because it was mixed with semi-pasty sludge, with 71.21% moisture and pH of 8.62, resulting in low efficiency in reducing total coliforms. Peracetic acid has a higher efficiency in the inactivation of microorganisms when mixed to sludge with 98% of moisture and the mixture is subjected to a time of contact of 30 minutes at room temperature (Barros *et al*., 2011).

In the model of subdivided plots for pH attribute, a significant change was verified between main treatments (limed sludge and homogenized sludge with peracetic acid, quaternary ammonium salts, sodium hypochlorite and pure sludge) when averages were compared by Scott-Knott Test, highlighting accented effect among secondary treatments (times) to pH parameter; there was no interaction between main factor and secondary factor concerning the analyzed parameter (Fig. 01). In figure 01 it is possible to verify that, in the beginning, sludge presented pH 8.65. Once the experiment was initiated, limed sludge has raised pH to levels superior to 12.00, but there was no significant change between evaluated treatments, thus, adding hygienization means (peracetic acid, quaternary ammonium salts and sodium hypochlorite) did not modify sewage sludge's pH. However, limed slugde presented better averages with pH above 12.00 throughout experimental cycle.

The average values of pH registered during the experimental period are presented in figure 01. Limed sludge has scored the higher pH averages with values above 12.0 at 7, 14 and 21 days. Materials treated with peracetic acid, quaternary ammonium salts, sodium hypochlorite and the pure sludge have not presented great variations on pH levels at 7, 14 and 21 days, registering average values between 7.56 and 8.82, what indicates that the applied means did not alter sewage sludge's pH level.

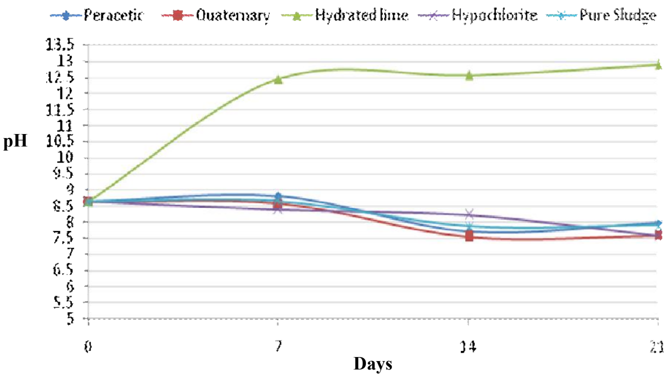

Figure 1. Potential of Hydrogen (pH) of sewage sludge subjected to different hygienization processes in periods of 7, 14 and 21 days

Throughout the research, normal temperature conditions, pure sludge temperature, temperature from sludge mixed with hygienization products and solar radiation and also concentration of total coliforms subjected only to solar radiation were monitored. The higher temperature values in hygienized sludge and pure sludge were registered on 08/07/2013, with averages from 23.92ºC to 30.43 ºC. Average external environment temperature was 20.39ºC during evaluation period, with the highest value, 22.89ºC, on 08/25/2013, and lowest, 14.97 ºC, on 08/16/2013 (Fig. 2). During measurements, external average temperature was 5.01 ºC lower than the temperature from the mass of hygienized sludge, contributing to the reduce of 2.7 logarithmic units during the period ot 21 days, but it was not sufficient to decrease the level of total coliforms to values below 10^3 MPN g^{-1} TS, which is the acceptable value for agricultural reuse of sludge concerning bacteriological characterization by Brazilian environmental legislation. Similar results are reported in studies from Mathiouclaris *et al.* (2009) as they affirm that a sludge subjected to solar drying has reduced levels of bacteria from the group of total coliforms in 2.3 logarithmic units.

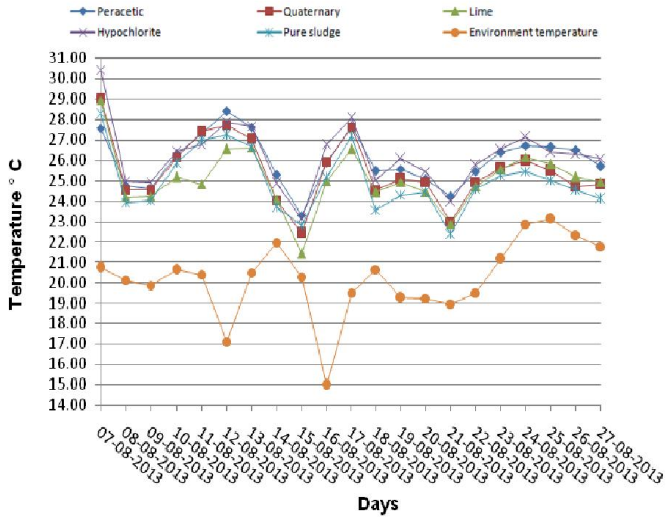

Figure 2. Temperature of sewage sludge homogenized with hygienization products and room temperature

Bux *et al.* (2001), while studing the hygienization of sewage sludge with solar energy obtained a decrease of 3 $\log_{10}$ of *E.coli* during a cycle of 21 days. Sypula *et al.* (2013) have worked with solar radiation on hygienization of sewage sludge during a cycle of 28 days and observed a great variability in the levels of insolation with values between 19.5 W/m² and 299.7 W/m², verifying also that there was a decrease in levels of total coliforms from 1.83 X 10^6 MPN g^{-1} TS to 4.0 X 10^4 MPN g^{-1} TS, values considered to be unsuitable for agricultural reuse of sewage sludge concerning bacteriological characterization. The adding of hygienization products had no influence on the temperature of sewage sludge mass and the variations that occurred during the evaluation period are from variations of ambient temperature and of local conditions as well. Lethal temperature for bacteria from the group of total coliforms is 55 ºC for 60 minutes (Tchobanoglus *et al*., 1993). Arthurson (2008) has mentioned that raising temperature to 70 °C for, at least, 1 hour, eliminates the majority of pathogenic agents in sewage sludge.

The low temperature registered in the mass of the sludge during experimental period is a result of the time of the year and local metrological conditions. The current study was carried out in a tropical region during winter, when prevail middle thermal index with variations from 20ºC and 24ºC and middle rainfall index of 10 mm and 50 mm. In these conditions, elimination of total coliforms to acceptable limits by brazilian legislation was not achieved. It is necessary additional treatment of sludge subjected to insolation to meet parameters stated by brazilian environmental standard to recycling sludge for agriculture. Salihoglu *et al*. (2007) has recommended liming as an additional treatment to sewage sludge subjected to solar drying. The distribution of solar radition registered during the experiment has presented small variability and oscillated from 18.27 Mj m^{-2} day^{-1} (211.45 W/m^2) to 23.44 Mj m^{-2} day^{-1} (271.29 W/m^2), (Fig. 03).

Ultraviolet rays have been shown to have bastericidal effect, however, it was not capable, alone, to reduce total coliforms to levels below limits of detection. Mathioudakis *et al*. (2009) have related that sewage sludge subjected to solar drying was not hygienized, despite going through a great amount of insolation from 950 W/m^2 to 1000 W/m^2.

After 21 days of the beginning of the process, sludge still presented a high concentration of total coliforms with average values of 5.85 logarithmic units (Fig. 03).

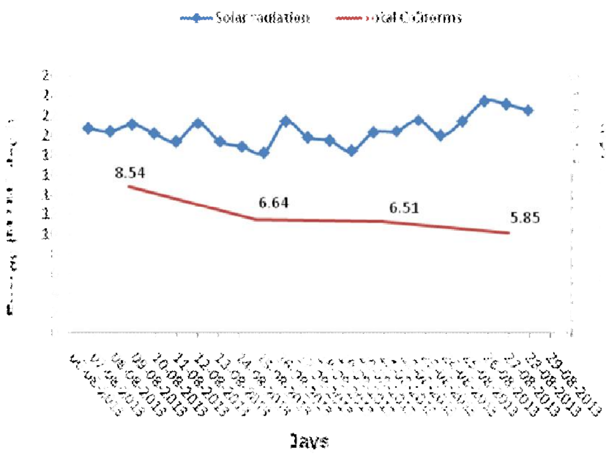

Figure 3. Concentration of total coliforms in pure sludge subjected to solar radiation. TC: Total Coliforms in Log (X + 10)

The exposure of pure sludge to a 0.1 m³ m^{-2} layer of solar radiation forces microorganisms to unfavorable proliferation and survival conditions. Beyond environmental factors, such as temperature, humidity and insolation, microorganisms present in the mass of sewage sludge have to compete with each other. Thus, it is expected that a higher time of exposure and a higher level of insolation result in a significant decrease in levels of total coliforms in seweage sludge. Total solid (TS) content has presented significant interaction between main factor (treatment) and secondary factor (time) (Table 04). The reduction in average content of humidity and increase in total solid content is enhanced by the time of exposure to solar rays to all evaluated treatments. Similar results are reported by (Andreoli *et al*., 2001). The better time to the reduction in levels of humidity and increase in level of total solids to all evaluated treatments was at 21 days after the beginning of the experiment.

Table 4. Total Solids of sewage sludge

Treatments	Time (days)			
	0	7 days	14 days	21 days
Control	28.7825*			
Peracetic acid		32.58 bB	52.746 bA*	56.77 bA*
Quaternary ammonium[1]		31.29 bB	60.20 bA*	68.98 bA*
Hydrated lime		43.01 bB	72.49 aA*	76.89 aA*
Sodium hypochlorite		34.44 bC	52.96 bB*	61.2 bA*
Pure sludge		32.56 bC	51.97 bB*	56.9 bA*

Means followed by the same lower case letters in the (Scott-Knott) column and the same capital letters in the (Tukey) column did not differ at the 5% significance level.* Significant at 5% by the Dunnett test. [1]= Dicetyl ammonium chloride, alkyl amido propyl chloride, dimethyl benzyl ammonium and water.

At 14 and 21 days after the beginning of the experiment it was observed that hydrated lime, applied in a quantity equal to 30% of the weight of the dry matter of the sludge, has presented contents of 72.49 dag kg kg^{-1} and 76.89 dag kg^{-1} of total solids respectively, which are higher than other hygienization means evaluated. The increase in total solids content occurs due to the reduction in humidity content by the adding of solids from hydrated lime itself and also by the precipitation of solids dissolved in sewage sludge, turning the sludge easier to handle. Similar results are reported in studies fromr (Bina *et al.,* 2004; Samaras *et al.,* 2008; Arthurson, 2008 e Farzadkia; Bazrfashan, 2014).

Knowledge of the amount of total volatile solids in sewage sludge is very important to evaluate its biological stability. Non-stabilized sludge presents strong foul odor being attractive to vectors and, therefore, is inappropriate for agricultural use. Volatile solids (VS) contents have presented differences between evaluated treatments, but there were no differences for times and for interactions between main factor and secondary factor.

It was observed that limed sludge has presented the lower contents of total volatile solids 35.,58 dag kg^{-1}, even lower than additional treatment which was 57,39 dag kg^{-1} (Table 05).

Table 5. Total Volatile Solids (VS) in sewage sludge

Time in days	Total Volatile Solids (VS)
Control	57.39 dag kg^{-1} NS
7 days	53.45 dag kg^{-1} NS
14 days	52.38 dag kg^{-1} NS
21 days	53.24 dag kg^{-1} NS
Treatments	
Peracetic acid	57.08 dag kg^{-1} B
Quaternary ammonium[1]	55.99 dag kg^{-1} B
Hydrated lime	35.58 dag kg^{-1} A*
Sodium hypochlorite	56.89 dag kg^{-1} B
Pure sludge	58.30 dag kg^{-1} B

Means followed by the same lower case letters in the (Scott-Knott) column and the same capital letters in the (Tukey) column did not differ at the 5% significance level. * Significant at 5% by the Dunnett test. NS = Non-significant [1]= Dicetyl ammonium chloride, alkyl amido propyl chloride, dimethyl benzyl ammonium and water.

The addition of hydrated lime, applied in a quantity equal to 30% of the weight of the dry matter of the sludge, has presented a decrease of 38% of volatile organics. To Mingnotte (2001), the reduction of at least 38% in volatile solids content due to addition of lime is common in the process of sewage sludge stabilization, what makes the residue non-attractive to vectors and without strong foul odors. Hydrated lime provides raising pH levels and an increase in calcium in the residue. According Arthurson (2008), free calcium ions provided by hydrated lime form complexes with species of odoriferous sulfur, such as hydrogen sulfide and organic mercaptan, resulting in a sludge with less unfriendly odors. The decrease of volatile organics with liming was also reported in works from Samaras *et al*., (2008). The addition of Ca $(OH)_2$ has raised mean pH of untreated sewage sludge from 8.65 to mean values above 12.0 during the 21 days cycle. Mingnotte (2001) has mentioned that sludge stabilization is achieved when the pH from sewage sludge is kept with values above 12.0 for at least 2 hours.

Conclusion

Limed sludge, with a quantity equal to 30% of the weight of the dry matter of the sludge, has provided the highest levels of pH due to its accented alkalinity, has reduced the concentration of total coliforms in more than 99.99%, decreased the concentration of total volatile solids in 38% and has increased the content of total solids, being appropriate to the hygienization of sludge concerning its bacteriological characterization and stabilization. The temperature increase provided by solar radiation was not enough, by itself, to reduce the level of total coliforms to values below 10^3 MPN g^{-1} TS, demanding additional treatments in order to achieve a complete hygienization according to the brazilian environmental legislation. Peracetic acid, quaternary ammonium compounds and sodium hypochlorite have not reduced the concentration of total coliforms to levels lower than 10^3 MPN g^{-1} TS due to the low humidity content of the sludge, what hampers the contact of the antimicrobial agent and microorganisms present in the sludge.

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