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Treatment of Sewage Sludge Generated in Municipal Wastewater Treatment Plants

CÉLIA R. G. TAVARES,* CLÁUDIA T. BENATTI, AND BENEDITO P. DIAS FILHO

State University of Maringá,Av. Colombo, 5790, Bloco E46-09, Maringá-PR; CEP 87020-900, Brazil, E-mail: celia@deq.uem.br

Abstract

This study was designed to evaluate the performance of a cylindrical anaerobic digester in treating secondary sewage sludge. A series of three independent batch experiments was performed for a total operation time of 60 d. The system of anaerobic digestion showed stability conditions, with no noticeable scum or foaming problems. The chemical oxygen demand reduction reached 29, 21, and 45% in sludge and 95, 85, and 82% in supernatant for the three experiments, respectively. Total coliform bacteria levels in the digester ranged from 10^4 to 10^5 in influent sludge and from 10^4 to 10^3 in effluent sludge, with an average reduction of 90%. Fecal coliforms of the order of 10^4 were enumerated in influent sludge and those of the order of 10^0 were enumerated in effluent sludge, with an average reduction of 99.9%. The studied system had satisfactory results, showing that both organic matter and indicator bacteria levels substantially decrease when the sludge is submitted to anaerobic digestion.

Index Entries: Sewage sludge; anaerobic digestion; stabilization; characterization; coliform bacteria.

Introduction

Most primary treatment processes as well as secondary treatment sequences yield sludges, which must be disposed of in some adequate way. Secondary sludges consist predominantly of excess biomass produced in the biologic process. A substantial fraction of the polluting substances removed during wastewater treatment processes is ultimately found in these sludges. Therefore, these sludges should not be released to the environment prior to appropriate treatment *(1)*.

*Author to whom all correspondence and reprint requests should be addressed.

The amount of sludge produced by wastewater treatment plants is expected to increase dramatically, in both industrialized and emerging countries, as a result of extended sewerage and advanced wastewater treatment, although there are possibilities of reducing the volume of these wastewaters and improving the still poor engineering in many sanitation systems *(2)*. Treatment and/or disposal of sludges accounts for roughly half the total cost of sewage treatment. The choice of sludge treatments actually used is, in practice, strongly influenced by nontechnologic factors such as site locations and transportation costs *(3)*.

Anaerobic digestion is one of the most widely used sludge stabilization processes. It produces a relatively stable sludge at moderate cost and, as an added benefit, it produces methane gas. The purposes of anaerobic digestion are to produce stabilized sludge, reduce pathogens, reduce sludge quantity by partial destruction of volatile solids, and produce usable gas as a byproduct *(4)*.

There are few reports on anaerobic digestion of secondary sewage sludge, because it is believed that sludge has achieved stabilization inside the upflow anaerobic sludge blanket (UASB) reactor. However, the optimization of UASB reactors allows sewage treatment with low hydraulic retention time, and, therefore, the produced sludge may not achieve stabilization, and it may even be necessary to supplement the stabilization process out of the reactor *(5)*.

The end of the treatment sequence involves disposal of the remaining stabilized sludge. Sludge disposal methods involve either land disposal or incineration. Because of the agronomic value of the digested sewage sludges, their use in agriculture and for land reclamation is being encouraged. Sludge recycling is an attractive environmental alternative for both soil conservation and disposal of residue, but potential risks from accumulation of heavy metals and organic compounds, as well as pathogen contamination, must be considered *(6)*.

The aim of the present investigation was to evaluate the use of anaerobic digestion as a stabilization process for secondary sludges yielded by UASB reactors. A total of three independent batch experiments, carried out with an anaerobic digester at an operation time of 60 d, were evaluated through physicochemical and microbiologic analysis.

Materials and Methods

Influent Sludge

The experiments were carried out with sewage sludge without previous thickening obtained from one of the local municipal wastewater treatment plants (Maringá-Paraná, Brazil). The wastewater treatment system consists of screening/grit removal followed by the use of UASB reactors called RALF (a variation of UASB reactor). In the treatment sequence, in the wastewater treatment plant, the sewage sludge produced is spread on

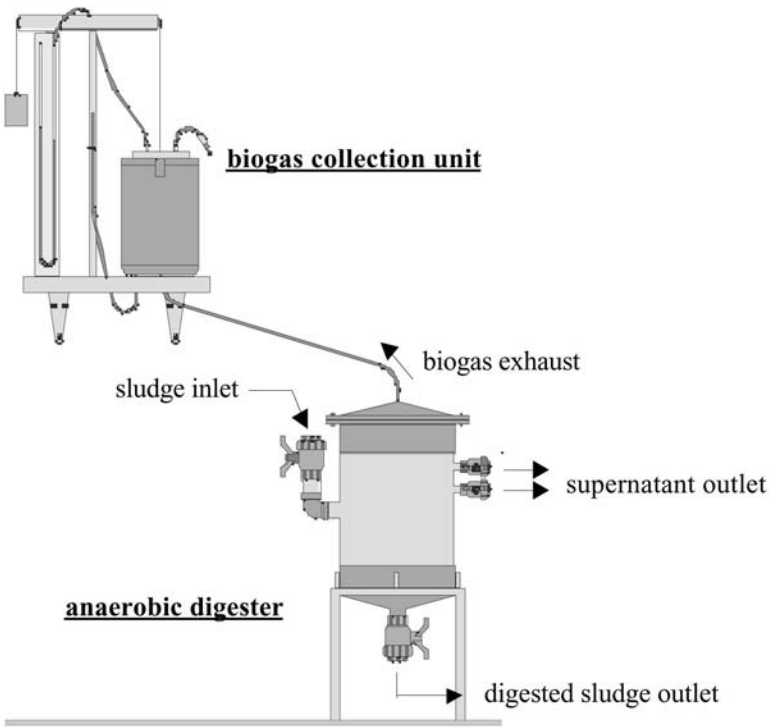

Fig. 1. Experimental unit

drying beds. These beds contain gravel for rapid drainage from the sewage slurry and are exposed to outside weather conditions. For the studied experiments, the sewage sludge was collected approximately every 3 to 4 mo during the discharge of exceeding sludge of the RALF reactor, before draining and drying in the drying beds.

Sludge Treatment Process

The experiments were performed using a 70-L cylindrical anaerobic digester with fixed cover manufactured in polyvinyl chloride and without mixing and temperature control (Fig. 1). A series of three independent batch experiments was performed for a total operation time of 60 d at room temperature. The biogas production was collected by water replacement in a gas collection unit, periodically measured, and later corrected to the standard pressure and temperature (1 atm and 0°C).

Microbial Enumeration

Total and fecal coliform bacteria were determined by multiple tube fermentation and enumerated by most-probable-number (MPN) estimates by using standard techniques *(7)*. Total and fecal coliform bacteria were also determined by pour plate method *(7)*. Samples of 0.1 mL of homogenized sludge and dilutions of these in saline solution (0.85%) were spread on agar plates. Media for bacterial analyses were obtained from Difco (Detroit, MI) or BBL Microbiology Systems (Cockeysville, MD). The solid media employed and the bacteria enumerated were as follows: Endo, coliform bacteria; EC, fecal coliform. The EC plates were incubated at 44.5°C, and the Endo plates were incubated at 37°C for 24–48 h. All colonies on plates were counted promptly after incubation. Numbers reported are an average of two replicate plates.

Analytical Methods

Measurements of total suspended solids (TSS), fixed suspended solids (FSS), volatile suspended solids (VSS), chemical oxygen demand (COD), oils and greases, and pH in sewage sludge and supernatant followed standard methods *(7)*. Nitrogen (Kjeldahl) was measured according to Adolfo Lutz Institute Analytical Norms *(8)*. Protein was measured according to the method of Lowry *(9)* using bovine serum albumin as protein standard. Volatile acids (VA) and alkalinity (AL) were measured according to the method of Silva *(10)*. Humidity and organic carbon were measured according to the ignition method of Kiehl *(11)*. For measurement of metals (Cu, Zn, Fe, and Cr) and nutrients (Mg, Ca, K, P, and Mn) the samples were digested according to the nitric-perchloric methodology *(12)* and with the exception of K and P, the readings of the elements were accomplished using an atomic absorption spectrometer GBC 932 AA (Scientific Equipment PTY). Potassium was measured by the emission flame photometry method and total phosphorous was measured through the metavanadate colorimetric method *(12)*. Biogas composition was monitored by gas chromatography on a Varian 1420 chromatograph (Porapak Q column, 2 m, 1/8 in, 50°C, carrier gas helium at a flow rate of 27 mL/min).

Results and Discussion

Table 1 reports the characteristics of the influent sludges of the three independent experiments. The ratio of volatile acids to alkalinity (VA/AL) represents a useful, dimensionless, yet sensitive digestion monitoring tool, which increases rapidly with a process upset and then decreases with recovery *(13)*. By maintaining a constant ratio below 0.25 of VA:AL, the buffering capacity of the system can be maintained *(4)*. VA:AL average ratios in the three independent experiments were 0.16, 0.20, and 0.13, respectively, showing that the digestion developed regularly (Fig. 2).

Figure 3A shows the VSS concentration in sludge and Fig. 3B in the suprenatant throughout the anaerobic digestion. Because of technical problems, the VSS content was not measured during the first presented experiment. VSS reduction reached 43 and 20% in sludge and 98 and 81% in the supernatant of the second and third presented experiments, respectively.

Figure 4A shows the COD concentration in sludge and Fig. 4B in the supernatant throughout the anaerobic digestion. COD reduction reached

Table 1
Characteristics of Influent Secondary Sludge
of Three Independent Experiments

Characteristic	Expt. 1	Expt. 2	Expt. 3
pH	7.2	7.5	7.4
Oils and greases (mg/L)	196	120	180
TSS (mg/L)	37,900	46,400	56,300
FSS (mg/L)	14,200	17,240	28,500
VSS (mg/L)	23,700	29,160	27,800
COD (mg/L)	51,825	32,858	65,675
Protein (mg/L)	18,739	9,811	13,542
Humidity (%)	93	95	92
Organic Carbon (%)	33	35	30
AL (mg $CaCO_3$/L)	508	442	781
VA (mg CH_3COOH/L)	126	109	130
Cu (mg/kg)	393	280	245
Zn (mg/kg)	1787	2023	431
Fe (mg/kg)	38,982	48,715	63,290
Cr (mg/kg)	103	87	42
Mn (mg/kg)	228	601	274
Nitrogen (Kjeldahl) (%)	3.5	3.6	3.3
P (mg/kg)	8114	6715	7117
K (mg/kg)	982	1281	1005
Ca (mg/kg)	20,643	15,445	21,027
Mg (mg/kg)	4081	2963	3704

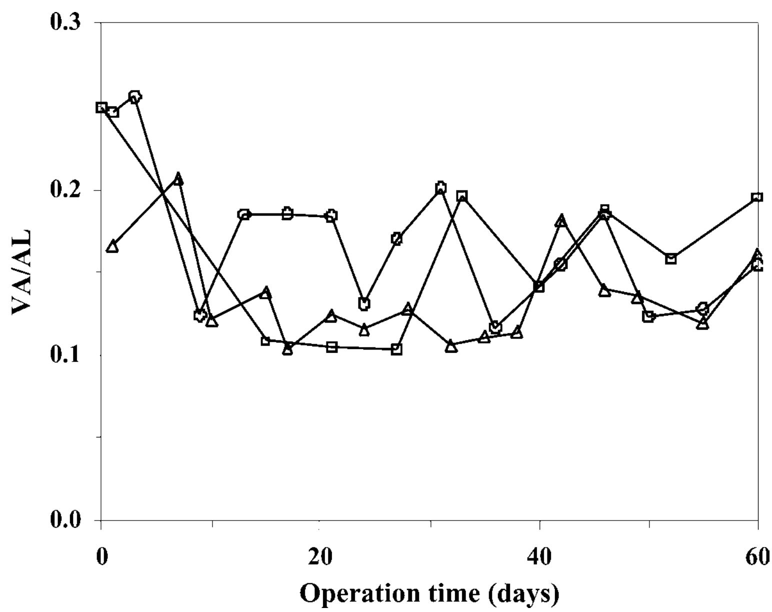

Fig. 2. VA:AL average ratio vs digester operation time for three independent batch experiments: (□) experiment 1; (○) experiment 2; (△) experiment 3.

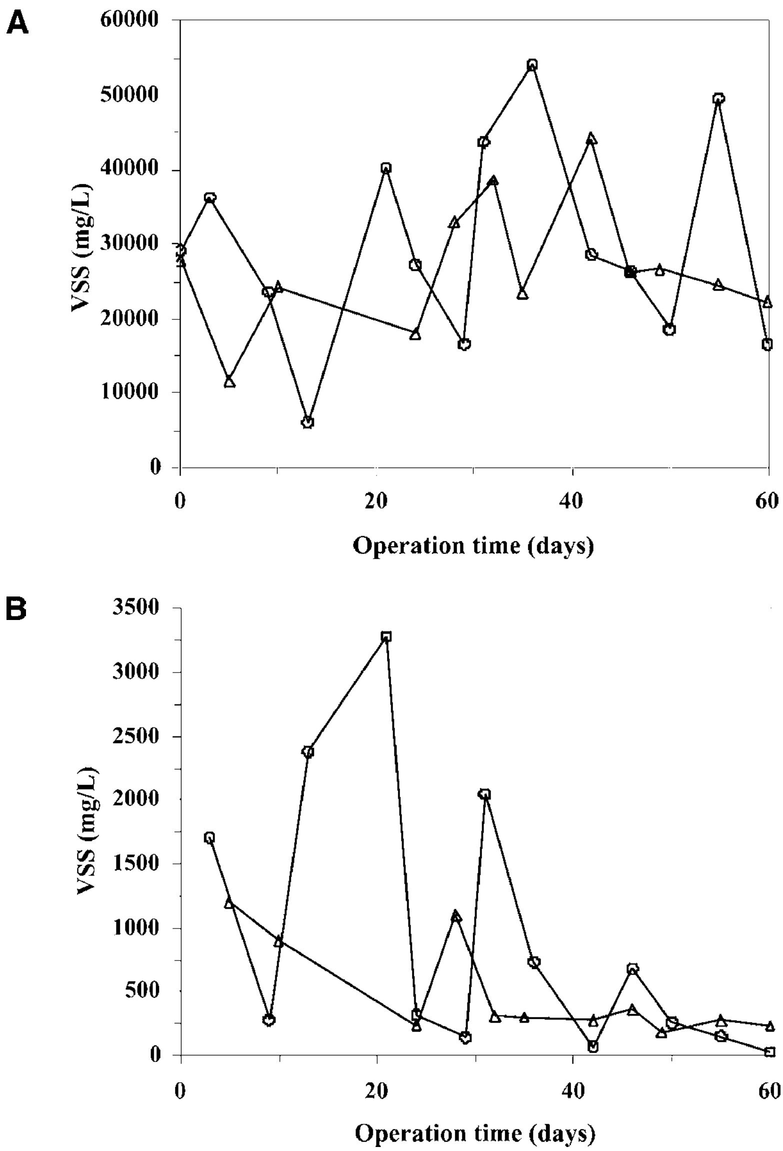

Fig. 3. VSS concentration in **(A)** sludge and **(B)** supernatant vs digester operation time for batch experiments 2 (○) and 3 (△).

29, 21, and 45% in sludge and 95, 85, and 82% in the supernatant of the three independent experiments, respectively. This low COD reduction achieved in the sludge of all experiments may be attributed to the transformation that occurs in the process. First, organic matter is transformed into other compounds such as organic acids that contribute to its COD content measure, and, second, these are transformed into mineralized organic matter, reaching sludge stabilization, that also contributes to its COD content measure. The higher COD reduction achieved in the supernatant of all experi-

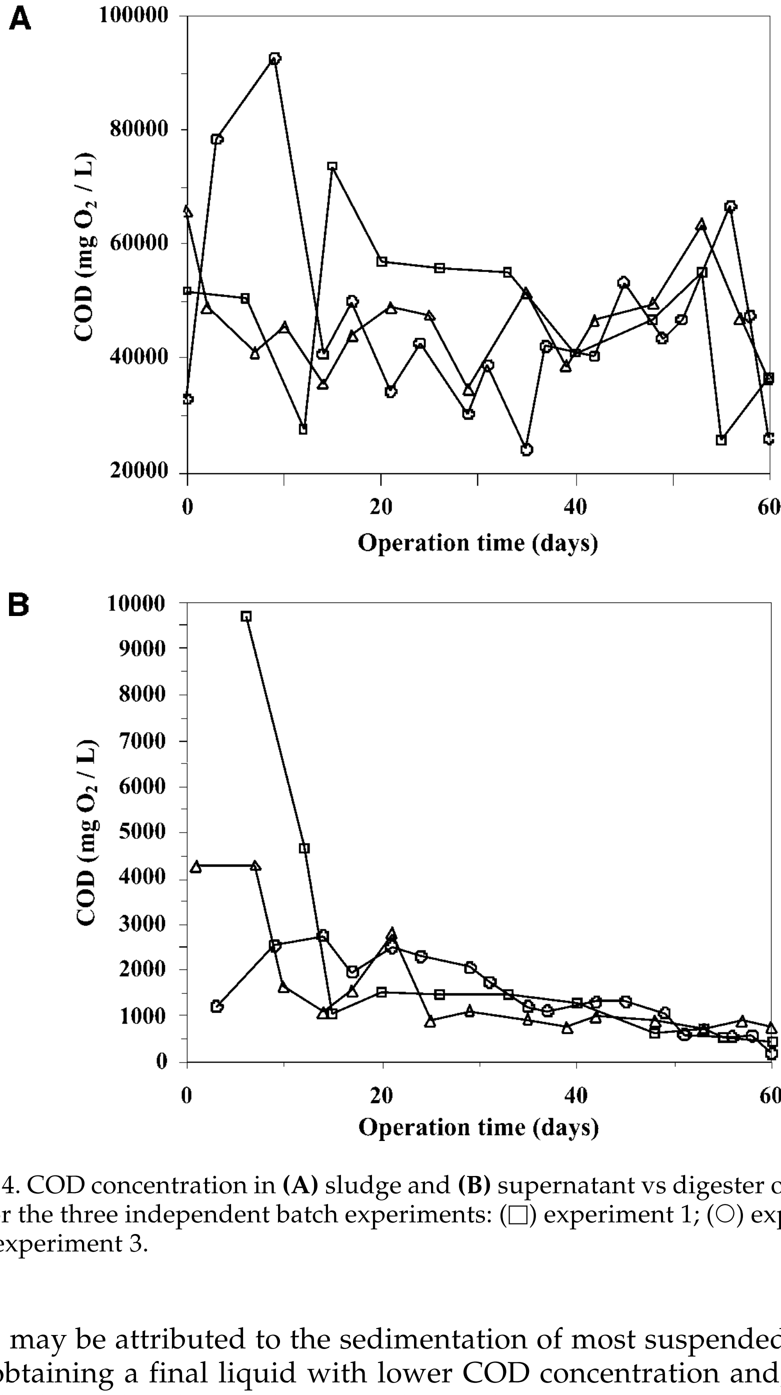

Fig. 4. COD concentration in **(A)** sludge and **(B)** supernatant vs digester operation time for the three independent batch experiments: (□) experiment 1; (○) experiment 2; (△) experiment 3.

ments may be attributed to the sedimentation of most suspended solids, thus obtaining a final liquid with lower COD concentration and, consequently, lower biochemical oxygen demand concentration.

All three batch experiments were operated at ambient temperatures with an average temperature throughout the anaerobic digestion of 23.1, 24.6, and 25.2°C (daily average temperature basis), respectively (data not shown). For the first and second experiments presented, daily biogas production measured throughout the anaerobic digestion had an average composition of 87% methane, 13% carbon dioxide. This result may indicate the dissolution of carbon dioxide in water of the biogas collection unit. In the third experiment, biogas was collected by water replacement in acidified water (pH 2.0) to minimize the dissolution of carbon dioxide. Daily biogas production measured throughout the anaerobic digestion presented an average composition of 74% methane, 26% carbon dioxide. Daily biogas production is shown in Fig. 5. These results are in agreement with data in the literature, such as the typical proportions of methane (70–80%) and carbon dioxide (20–30%) in produced biogas by anaerobic digestion of domestic wastewaters reported by Chernicharo *(14)*.

From an agricultural point of view, the use of sewage sludges as fertilizers has restricted application based on their heavy metal content. Such limitations were published in the European Directive 86/278/EEC *(15)*. Table 1 shows that none of the heavy metals measured was over the maximum established limits. Furthermore, Table 1 shows that sludges have high contents of organic matter and nitrogen, with a neutral pH, and moderate contents of phosphorus and potassium. Therefore, sludges have a fertilizer power despite the need for complementation with mineral sources owing to their unbalanced nutritious contents.

Coliform organisms are rod-shaped bacteria, that are present in the human intestinal tract *(1)*.The coliform bacteria group (which is divided into total and fecal coliform bacteria) is frequently associated with enteric pathogen organisms, and it has been shown to be a useful indicator of the presence of fecal contamination. The total coliform group includes many bacteria of nonfecal origin; therefore, the fecal coliform group, which is differentiated from the total coliform group only by its ability to grow at elevated temperatures (44.5°C), has become the most important microbial indicator of water quality *(16)*. The most-probable number procedure is a usual test for coliforms, based on their ability to ferment lactose broth, which produces gas.

Figure 6 shows the total and fecal coliform groups enumerated in the three independent batch experiments throughout the digester operation time based on the MPN procedure (MPN/mL). Total coliforms in the digester ranged from 10^4 to 10^5 in influent sludge and from 10^4 to 10^3 in effluent sludge, with an average reduction of 90.2%. Fecal coliforms of the order of 10^4 were enumerated in influent sludge and of the order of 10^0 were enumerated in effluent sludge, with an average reduction of 99.9%. Fecal coliform bacteria levels in the digester effluent sludge showed a small population of the fecal coliform group, and no bacterial growth was observed in the minor dilution (10^{-1}), which may indicate numbers smaller than 10 MPN/100 mL. The reduced number of fecal coliform bacteria in the digester effluent may indicate that the system is working efficiently, with a significant reduction of pathogen in the sludge.

Coliform group population numbers per gram (dry wt) were also based on colony counts on solid media (CFU/g). Coliform bacteria in the

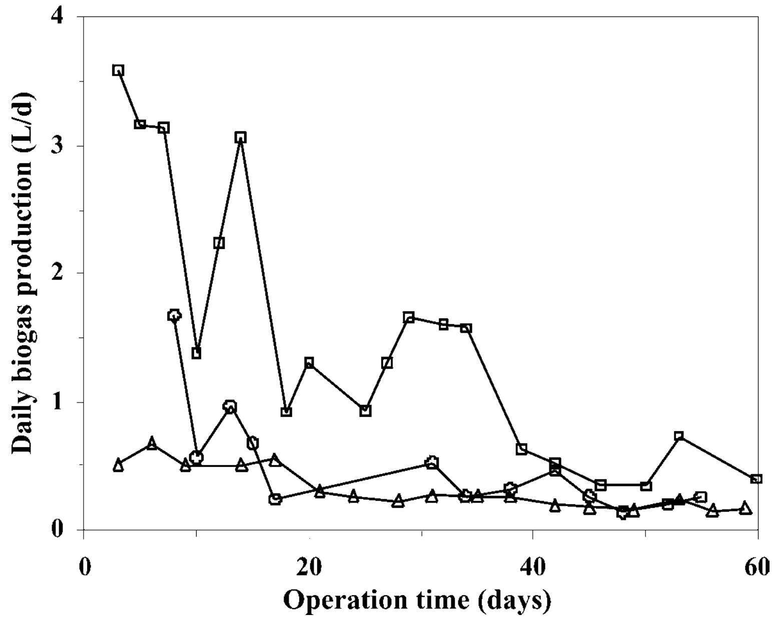

Fig. 5. Daily biogas production vs digester operation time for three independent batch experiments: (□) experiment 1; (○) experiment 2; (△) experiment 3.

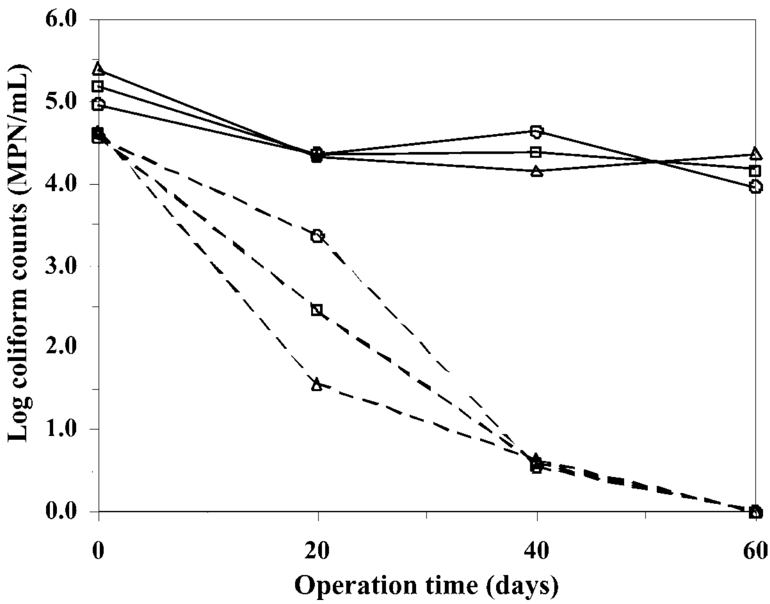

Fig. 6. Total (—) and fecal (– – –) coliform groups in sewage sludge based on most-probable number procedure vs digester operation time for three independent batch experiments: (□) experiment 1; (○) experiment 2; (△) experiment 3.

digester were enumerated on the order of 10^6 in the influent sludge and 10^5 in the effluent sludge, reaching a reduction of 96.3%. Fecal coliforms in the digester were enumerated on the order of 10^5 in the influent sludge and 10^3 in the effluent sludge, reaching a reduction of 99.6%.

In the state of Paraná, Brazil, the state sanitation company classifies the sludge according to the American CFR Part 503 regulation and specifies a class A sludge ($<10^3$/g dry wt basis) for urban sludge spreading on agricultural land *(17)*. The presented data show that the fecal coliforms in influent sludge must be reduced to below detectable levels to reach the land-use criteria. Therefore, the effluent sludge can fulfill the criteria for category A sludge, especially if the entire process, such as the anaerobically digested sludge analyses after being air-dried on drying beds has been considered.

Conclusions

The secondary sewage sludge produced by the wastewater treatment plant did not achieve stabilization inside the UASB reactor. Thus, these sludges need to undergo a stabilization process before being spread on drying beds. In addition, the heavy metal content is not the limiting factor in the use of these sludges as a soil conditioner. However, the phosphorous and potassium content of sludges may be too low to satisfy specific plant uptake requirements in some land application systems. Finally, the studied system presented satisfactory results, showing that the number of indicator bacteria substantially decreases when the sludge is submitted to anaerobic digestion. However, better results would have been achieved if the entire process, such as the anaerobically digested sludge analyses after being air-dried on drying beds, had been considered.

Acknowledgments

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