Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2017.20850

91 (2017) 240–244
October

Fertilizer effect of UASB (55°C) effluent with limestone as fixed bed treating vinasse on development of *Brachiaria brizantha* cv. Xaraés

F.J.C. Magalhães Filho[a,*], L.G.F. Gregio[a], J.B. de Azevedo[b], A.S. de Paiva[b], D. de O. Guilherme[b], M.P. Cereda[b]

[a]*Department of Sanitary and Environmental Engineering, Dom Bosco Catholic University, 6000 Tamandaré Avenue, 79.117-900, Campo Grande, MS, Brazil, emails: fernandojcmf@hotmail.com, fernando@ucdb.br (F.J.C. Magalhães Filho), luisgregio@gmail.com (L.G.F. Gregio)*
[b]*Centre of Technology and Agribusiness (CeTeAgro/UCDB), Dom Bosco Catholic University, Campo Grande, MS, Brazil, emails: cleiapaiva@ucdb.br (A.S. de Paiva), denilsond@gmail.com (D. de O. Guilherme), cereda@ucdb.br (M.P. Cereda)*

Received 23 December 2016; Accepted 23 April 2017

ABSTRACT

Vinasse is a residual liquid obtained from the production of sugar and alcohol, which can be used in fertirrigation. However, if untreated, its use can pollute soil and water. The objective of this study was to evaluate a thermophilic (55°C) upflow anaerobic sludge blanket treating vinasse using a fixed bed with limestone as a buffer agent to avoid rapid acidification and the initial effect of applying the effluent to irrigate *Brachiaria brizantha* cv. Xaraés. Using treated vinasse generates biogas and effluent with lower pollutant loads that can be used in irrigation. This allows vinasse to be used in forage, for livestock food development and production systems. The inoculum (cattle manure) demanded 140 d to stabilize and the reactor had a chemical oxygen demand removal of 99% in the thermophilic range, and the gas production increased >40%. The use of raw vinasse did not significantly influence the vegetative development of *Brachiaria brizantha* cv. Xaraés. The treated vinasse benefited the growth after 40 d after sowing (“second cut”).

Keywords: Anaerobic digestion; Fertirrigation; Agro-industrial wastewater; Biogas; Livestock

1. Introduction

The production of ethanol and sugar from sugarcane is a common practice, and this process results in great quantities of residues such as ashes, bagasse, gas emissions, and vinasse [1]. Sugarcane vinasse is a residue of great concern, due to its quantities, for each liter of alcohol produced, 12–14 L of vinasse is generated, and is a pollution potential for soil and water. The inadequate disposal of vinasse has received attention for decades, due to environmental problems associated to this practice. The large quantities of vinasse produced has enabled alternative treatments and uses to be developed, such as the recycling of vinasse in fermentation, fertirrigation, concentration by evaporation, and yeast and energy production. However, there is a lack of studies on the difference between raw and treated vinasse and its effect on crop productivity [2].

The characteristics present in vinasse are: a high organic load that can exceed 100.0 g L^{-1} of chemical oxygen demand (COD) [3], a pH around 4–5, and an output temperature of approximately 90°C. In this sense, the environmental impact can be minimized with proper treatment, since there is potential for a fertilizer (nitrogen, phosphorus, and potassium). The use of raw vinasse improves agricultural productivity and it is a common practice adopted in Brazil [4].

The upflow anaerobic sludge blanket (UASB) process has been successfully used for different types of wastewater [5]. This technology can be used for energy production and the

* Corresponding author.

Presented at the 13th IWA Specialized Conference on Small Water and Wastewater Systems & 5th IWA Specialized Conference on Resources-Oriented Sanitation, 14–16 September, 2016, Athens, Greece.

1944-3994/1944-3986

reduction of organic matter in waste [6]. The use of other technologies such as facultative or anaerobic ponds and trickling filters, are not suitable, for causing clogging and requiring large areas of land, respectively.

In Brazil, with the energy matrix based on hydropower [7], and climate change increasingly evident, it is important to have alternative methods to generate energy, and to reduce greenhouse gases, with the objective of sustainable development [8]. The use of aerobic technologies becomes infeasible for three reasons: (i) operational and maintenance costs for nutrient removal (such as nitrogen) are expensive, (ii) current legislation does not present restrictions, except for allowing fertigation; and (iii) large amounts of sludge is generated during post-treatment.

However, it is not common to treat vinasse, especially in Brazil. Its application to soil as a fertilizer for sugarcane crops is currently the most common practice. This can cause impacts such as soil salinization, metal and sulfate leaching, groundwater contamination, malodors, and the attraction of insects [9]. The low pH, electrical conductivity, and chemical elements in vinasse cause changes in physical–chemical properties of rivers and lakes with frequent discharges over a long period, and have adverse effects on agricultural soils and biota [2].

Thus, one option is to use a UASB in the thermophilic range [6,9,10], since vinasse in the output process which enters the reactor at a temperature above 60°C, which may allow the reactor to operate with a better performance. In addition, the treated effluent can irrigate forage crops (used as feed in livestock production) and avoid polluting and the cause of environmental impacts. Therefore, the adoption of such technology in biorefineries could potentially lead to profits from energy, environmental, and economic prospects, thus optimizing the plants in terms of sustainability [8,9].

In this sense, this study presents a possibility for the integration of agriculture (sugarcane production) and livestock (fodder crop production), in addition to energy generation and the reuse of agro-industrial effluent of higher quality, preventing soil, and water pollution while adding value to the residue.

The objective was to evaluate an initial operation of a thermophilic (55°C) UASB treating vinasse using a fixed bed with limestone as a buffer agent to avoid rapid acidification and the effect of applying the effluent to irrigate *Brachiaria brizantha* cv. Xaraés.

2. Materials and methods

2.1. Thermophilic (55°C) UASB

The two lab-scale reactors consisted of a 1 m high polyvinyl chloride cylinder with a 0.20 m diameter (Fig. 1). The total volume of the reactor was 27 L and 50% of it was filled with limestone (13.5 L; size: 25–19 mm) as a fixed bed to maintain a near neutral pH. The reactor was inside of a metallic drum (120 L) with engine oil that was heated to 55°C. The biogas produced was collected in a gasholder floating in a solution of 3% H_2SO_4 and 25% NaCl to remove CO_2, which allowed the measurement of biogas production, similar to the study of El-Mashad et al. [6].

The total time the system ran before reaching steady state was 140 d. After reaching steady state the system ran for 30 d at 36°C and then 30 d for each temperature range (40°C, 44°C, 48°C, 52°C and 55°C), 180 operational days.

2.2. Substrate and anaerobic sludge

The sugarcane vinasse used originated from an ethanol factory (located 400 km from the study site) with an initial temperature of 100°C and after 6 h the temperature dropped to 60°C and had a pH level of 4.3. This pH level in this initial evaluation allows the vinasse to be used in natura (raw vinasse). The vinasse was stored at –20°C in 20 L bottles. The UASB reactors were inoculated to one-third of their total volume with an adapted anaerobic sludge from cattle manure (8.0 kg) with water (20.5 L), common in rural areas. The dilution used in these experiments was to mitigate the high total solids (TS) and the ammonia concentration effect, according to El-Mashad et al. [6].

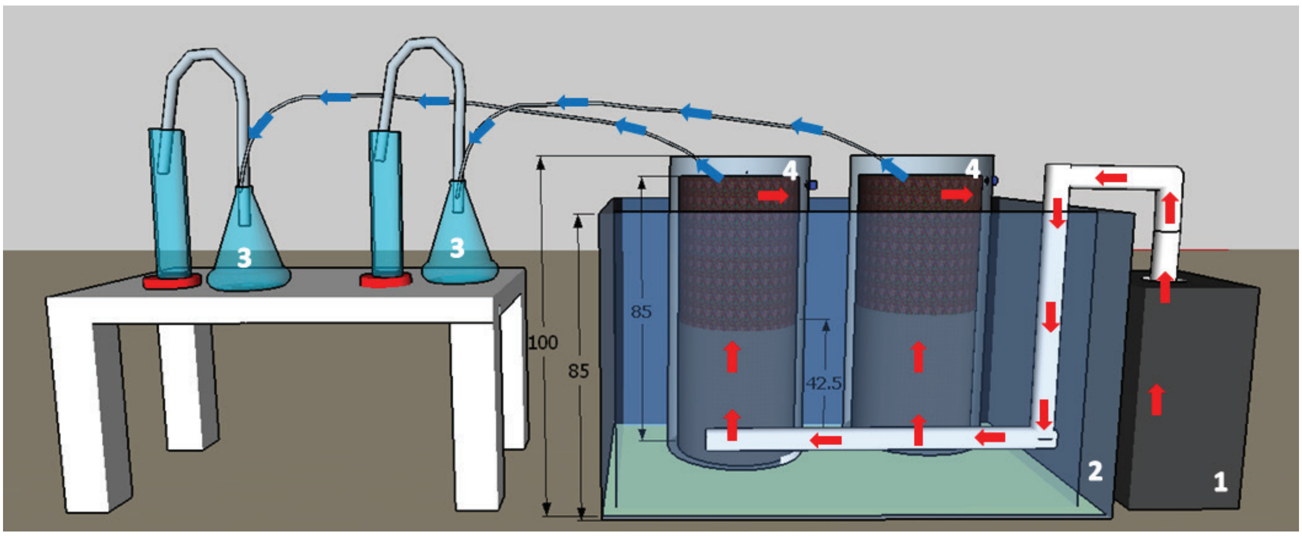

Fig. 1. Experimental setup: (1) equalization tank and heater with pump system; (2) metallic drum; (3) gasholder floating; and (4) effluent output. Red line: vinasse flow; blue line: biogas flow; R1 and R2: UASB (55°C); dimensions in centimeters.

2.3. Vinasse samples

Samples of vinasse influents and effluents (Table 1) of the reactor were analyzed three times a week. The samples were analyzed in triplicate by the following parameters: COD, TS, total volatile solids (TVS), total fixed solids, alkalinity, volatile acidity, and pH. This process was carried out according to the Standard Methods for the Examination of Water and Wastewater [11].

2.4. Initial growth of *Brachiaria brizantha* cv. Xaraés and statistical analysis

There were four treatments used: control (without fertilizer addition); fertilization; raw vinasse (535 m^3 ha^{-1}), and treated vinasse (567 m^3 ha^{-1}). They were used with a randomized block design with six repetitions. The vinasse was applied 15 d after sowing and two cuts were made during the experiment (after 40 and 80 d). At the end of the evaluated cycle (80 d), the seedlings were evaluated for height, fresh and dry total mass, fresh and dry leaf mass, and fresh and dry stem mass. The multiple mean comparisons within treatments were performed using Tukey's test at a 0.05 error level.

The soil collected in this study presents a sandy medium texture (Table 2), according to the criteria of the Brazilian System of Soil Classification [12].

3. Results and discussion

3.1. Thermophilic UASB operation

Table 3 shows the results of the average values during the operation of the UASB reactors. The lime was effective in alkalinity formation in the medium. Even with the gradual increase in temperature (to obtain the desired temperature 55°C) and the organic load applied, the reactors were effective in removing organic matter (COD, solids) and producing biogas. With temperatures above 48°C the reactors showed values of above 90% efficiency in COD removal and TVS. These values are higher than the results obtained by Ribas et al. [13], who conducted a study similar to vinasse treatment with a thermophilic temperature using $NaHCO_3$ as an alkalinity source, and observed a maximum organic matter removal of 70%.

With a thermophilic (55°C) anaerobic treatment of alcohol distillery wastewater (sugarcane vinasse), using a 140 L UASB, Harada et al. [10] obtained 67% and 80% for COD and BOD removal, applying 10.0 kg COD m^{-3} d^{-1}, for a period of 430 d. However, Souza et al. [14] applying 25–35 kg COD m^{-3} d^{-1} obtained 72% COD removal in a thermophilic range in a pilot plant (75 m^3) with vinasse and almost no soda was necessary for pH control.

Table 1
Concentration of raw vinasse applied in UASB and concentration of treated vinasse used to *Brachiaria brizantha* cv. Xaraés growth

Parameters	Concentration raw vinasse	Concentration treated vinasse
pH	4.3	5.3
COD (g L^{-1})	16.7	2.0
Total solids (mg L^{-1})	14,253.0	1,464.0
Total volatile solids (mg L^{-1})	12,652.3	504.0
Total fixed solids (mg L^{-1})	1,477.0	960.0
Total phosphorus (mg L^{-1})	17.0	7.0
Total nitrogen (mg L^{-1})	40.1	3.1
Calcium (mg L^{-1})	60.9	47.5
Iron (mg L^{-1})	4.6	1.9
Potassium (mg L^{-1})	420.0	223.0
Magnesium (mg L^{-1})	105.9	51.3
Manganese (mg L^{-1})	17.4	0.9
Zinc (mg L^{-1})	3.3	0.1

3.2. Development of *Brachiaria brizantha* cv. Xaraés

The use of raw and treated vinasse did not significantly influence the vegetative development of *Brachiaria brizantha* cv. Xaraés during the first and second crop (Table 4). In the second cut, plant growth with treated vinasse was significantly higher compared with the control sample (without fertilizer), which indicates the benefit of its usage to culture advanced stages.

The low plant growth relative to treatment with chemical fertilizer can be associated with the soil pH being below 4.5. The ideal range for the absorption of most nutrients by plants is around 6.0 [15]. This lower development of *Brachiaria brizantha* cv. Xaraés is a function of pH and can be justified when compared with plants that did not use fertilized soil, which had a pH of 4.97.

3.3. Difference between products

As there is no significant difference between the treated and raw vinasse about height measurements and fresh and dry leaf and stem mass. The results show that treatment does not change the nutritional properties of the waste, enabling the use of treated effluent. In addition to this factor, the anaerobic process is also advantageous for potential energy (biogas production).

Table 2
Physicochemical analysis for the soil

pH	4.97
Organic matter, g dm^{-3}	6.86
K, cmol dm^{-3}	0.03
Ca + Mg, cmol dm^{-3}	0.3
Al + H, cmol dm^{-3}	2.34
S, %	0.33
T, %	2.67
V, %	12.36
Fe, mg dm^{-3}	144.96
Mn, mg dm^{-3}	12.02
Zn, mg dm^{-3}	0.94
Cu, mg dm^{-3}	0.9
B, mg dm^{-3}	0.09

Table 3
Start-up UASB reactor operation results: removal (%) of COD and solids; pH, alkalinity, and volatile acids; and biogas production compared with organic load, hydraulic detention time, and temperature range

°C	Days	HDT	OL	COD (%)	TS (%)	TVS (%)	TFS (%)	Alk.	VA	pH	Biogas ($mL\ L^{-1}\ d^{-1}$)
36 ± 2	0–29	7	0.5	70.6 ± 3.2	69.0 ± 5.3	78.6 ± 4.7	20.7 ± 6.2	35.0 ± 12.1	242.2 ± 16.1	8.4 ± 0.9	125 ± 15
40 ± 2	30–59	5	1.3	75.1 ± 2.1	81.9 ± 3.7	86.5 ± 2.2	27.6 ± 4.3	50.0 ± 10.3	292.4 ± 14.9	8.1 ± 0.8	165 ± 25
44 ± 2	60–89	5	3.3	77.3 ± 8.5	82.0 ± 9.2	88.1 ± 4.1	34.5 ± 3.7	80.0 ± 9.8	74.4 ± 12.7	7.8 ± 0.5	200 ± 22
48 ± 2	90–104	4	6.7	91.7 ± 1.9	91.7 ± 3.1	91.0 ± 2.9	35.0 ± 4.9	120.0 ± 11.6	60.0 ± 13.4	7.7 ± 1.0	350 ± 35
52 ± 2	105–119	3	8.5	98.2 ± 1.0	84.0 ± 2.9	94.5 ± 1.9	35.5 ± 2.5	150.0 ± 14.7	83.6 ± 7.1	8.7 ± 1.1	500 ± 15
>55	120–141	3	11.7	99.5 ± 0.9	89.7 ± 1.8	96.0 ± 2.5	35.7 ± 1.7	170.0 ± 15.5	76.8 ± 8.2	8.5 ± 1.4	500 ± 18

°C: temperature; HDT: hydraulic detention time (d); OL: organic load (kg COD $m^{-3}\ d^{-1}$); COD: chemical oxygen demand removal (%); TS: total solids removal (%); TVS: total volatile solids removal (%); TFS: total fixed solids removal (%); Alk.: alkalinity (mg $CaCO_3\ L^{-1}$); and VA: volatile acidity (mg $CH_3COOH\ L^{-1}$).

Table 4
Height measurements and fresh and dry leaf and stem mass, in the first and second cut

Treatment fertilizer	Height	FTM	LFM	SFM	DTM	LDM	SDM
	cm	g					
First cut							
Control	42.17 b	2.27 b	2.09 b	0.19 b	0.67 b	0.39 b	0.03 b
Chemical fertilizer	92.17 a	47.80 a	37.42 a	9.93 a	11.47 a	9.43 a	1.97 a
Raw vinasse	36.92 b	2.97 b	2.71 b	0.24 b	0.60 b	0.55 b	0.02 b
Treated vinasse	37.92 b	2.04 b	2.0 b	0.06 b	0.37 b	0.37 b	0.07 b
CV	22.03	34.04	31.69	32.51	20.85	22.42	17.73
Second cut							
Control	69.33 c	42.02 b	26.42 b	15.62 b	8.37 b	5.78 b	2.59 b
Chemical fertilizer	88.83 a	123.18 a	72.97 a	50.80 a	32.84 a	21.06 a	11.79 a
Raw vinasse	69.67 bc	45.53 b	28.20 b	17.30 b	9.36 b	6.42 b	2.94 b
Treated vinasse	78.33 b	41.76 b	25.72 b	16.65 b	8.83 b	5.76 b	3.07 b
CV	6.96	26.15	24.70	27.21	23.50	22.32	23.53

Means followed by the same letter in the column do not differ from Tukey's test ($p > 0.05$). FTM: fresh total mass; LFM: leaf fresh mass; SFM: stem fresh mass; DTM: dry total mass; LDM: leaf dry mass; SDM: stem dry mass; and CV: coefficient of variation.

The biogas production increased with COD loading until 55°C, approximately 75%. The relationship between the COD removal rate and the biogas production rate is $Y = 0.258X$. The ratio of biogas was similar to methane production per COD removal (0.29 $Nm^3\ CH_4$ kg COD^{-1} removed), from the slope of the linear regression, according to Harada et al. [10].

3.4. *Vinasse options considering fertirrigation in areas with sugarcane*

Evaluating the present nutrient composition in the vinasse (raw and treated) with the nutritional needs of *Brachiaria brizantha* cv. Xaraés, it is observed that the low concentration of total nitrogen is not presented as a limiting factor, because the established grassland does not mineralize organic matter for N to be available.

When evaluating the application of vinasse in sugarcane culture (pure or consortium), where the vinasse is applied as a fertilizer, there is a need to use urea as a complementary fertilizer on the culture due to its nutritional needs [16]. Considering this factor, and the possibility of biogas power generation, an option would be to add urea measurements to the anaerobic treatment with or without limestone [16,17]. Urea is hydrolyzed during the anaerobic digestion, forming NH_3 and CO_2, increasing alkalinity within the reactor. Furthermore, the effluent would be suitable to use in soils cultivated with sugarcane.

4. Conclusions

The inoculum (cattle manure) demanded 140 d to stabilize (start-up). The reactor removed 99% of the COD in the thermophilic range and showed high solids removal.

With an increasing temperature (mesophilic–thermophilic) the gas production increased >40%.

The use of raw vinasse did not significantly influence the vegetative development of *Brachiaria brizantha* cv. Xaraés. The treated vinasse benefited the growth after 40 d after sowing ("second cut").

The use of treated vinasse in a UASB (55°C) provides biogas generation and effluent for irrigation with lower pollutant loads to the soil and water, allowing its usage in the development of forage crops for livestock food production systems.

References

[1] G. Vaccari, E. Tamburini, G. Sgualdino, K. Urbaniec, J. Klemes, Overview of the environmental problems in beet sugar processing: possible solutions, J. Cleaner Prod., 13 (2005) 499–507.

[2] C.A. Christofoletti, J.P. Escher, E. Correia, J.F.U. Marinho, C.S. Fontanetti, Sugarcane vinasse: environmental implications of its use, Waste Manage., 33 (2013) 2752–2761.

[3] A.C. Wilkie, K.J. Riedesel, J.M. Owens, Stillage characterization and anaerobic treatment of ethanol stillage from conventional and cellulosic feedstocks, Biomass Bioenergy, 19 (2000) 63–102.

[4] M.M.F. Ribas, M.P. Cereda, Stabilization of cassava wastewater during acidogenic phase in anaerobic reactor with sodium hydroxide (NaOH) and two sizes of dolomitic limestone, J. Root Crops, 29 (2003) 1–6.

[5] G. Lettinga, L.W. Hulshoff Pol, UASB process design for various types of wastewaters, Water Sci. Technol., 26 (1991) 877–886.

[6] H.M. El-Mashad, G. Zeeman, W.K.P. van Loon, G.P.A. Bot, G. Lettinga, Effect of temperature and temperature fluctuation on thermophilic anaerobic digestion of cattle manure, Bioresour. Technol., 95 (2004) 191–201.

[7] D. Pottmaier, C.R. Melo, M.N. Sartor, S. Kuester, T.M. Amadio, C.A.H. Fernandes, D. Marinha, O.E. Alarcon, The Brazilian energy matrix: from a materials science and engineering perspective, Renew. Sustain. Energy Rev., 19 (2013) 678–691.

[8] L. De Baere, Anaerobic digestion of solid waste: state-of-the-art, Water Sci. Technol., 41 (2000) 283–290.

[9] B.S. Moraes, M. Zaiat, A. Bonomi, Anaerobic digestion of vinasse from sugarcane ethanol production in Brazil: challenges and perspectives, Renew. Sustain. Energy Rev., 44 (2015) 888–903.

[10] H. Harada, S. Uemura, A.C. Chen, J. Jayadevan, Anaerobic treatment of recalcitrant distillery wastewater by a thermophilic UASB reactor, Bioresour. Technol., 55 (1996) 215–221.

[11] APHA, AWWA, WEF, Standard Methods for Examination of Water and Wastewater, 21st ed., 2005.

[12] Embrapa, Empresa Brasileira De Pesquisa Agropecuária, Centro Nacional de Pesquisa de Solos, Sistema Brasileiro de Classificação de Solos, 2nd ed., Rio de Janeiro, 2006.

[13] M.M.F. Ribas, F.A. Chinalia, E. Pozzi, E. Foresti, Microbial succession within an Anaerobic Sequencing Batch Biofilm Reactor (ASBBR) treating cane vinasse at 55°C, Braz. Arch. Biol. Technol., 52 (2009) 1027–1036.

[14] M.E. Souza, G. Fuzro, A.R. Polegato, Thermophilic anaerobic digestion of vinasse in pilot plant UASB reactor, Water Sci. Technol., 25 (1992) 213–222.

[15] N.K. Fageria, F.J.P. Zimmermann, Influence of pH on growth and nutrient uptake by crop species in an Oxisol, Commun. Soil Sci. Plant Anal., 29 (1998) 2675–2682.

[16] A.C. van Haandel, Integrated energy production and reduction of environmental impact at alcohol distillery plants, Water Sci. Technol., 52 (2005) 49–57.

[17] M.A. Boncz, E.L. Formagini, L.D.S. Santos, R.D. Marques, P.L. Paulo, Application of urea dosing for alkalinity supply during anaerobic digestion of vinasse, Water Sci. Technol., 66 (2012) 2453–2460.