Evaluation of anaerobic sludge activity in wastewater treatment plants in Nicaragua

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Abstract

Sludge of three municipal anaerobic wastewater treatment plants was evaluated. This study was initiated due to the low activity observed in the anaerobic wastewater treatment plants in Nicaragua. An additional goal to select one of them, if possible, as an inoculum for the brewery treatment plant was proposed. Two of these plants work with an Imhoff tank and one with a Septic tank followed by an anaerobic upflow filter. The study consisted in the characterization of biomass in terms of Specific Methanogenic Activity (SMA), Volatile Suspended Solids (VSS), density, pH, and redox potential (RP). The treated waters were also analysed for nutrients, heavy metals and the organic load. The substrate used in the experiments for determining the methanogenic activity was acetic acid. $NaHCO_3$ was added to maintain pH in the normal range of operation. The tests were carried out at a sludge load of 1.5 g VSS/l. The results indicate that treated wastewater does not have any impediment to proper development of microorganisms; no presence of toxic substances and enough essential nutrients were detected. The specific methanogenic activity of sludge (SMA) in the Imhoff tanks is relatively close and oscillates between 0.16-0.28 g CH4-COD/g VSS/day, and in the septic tank is 0.09 g CH4-COD/g VSS/day. These values agree with the methanogenic activity found in the literature for septic tanks (0.02-0.1 g CH_4-COD/gVSS/day). The highest methanogenic activity measured during the test was 0.28g CH_4-COD/g VSS/day in the sludge of the Imhoff tank in The Viejo city, so this sludge could be proposed as a seed for the brewery treatment plant.
Keywords: anaerobic treatment, sludge, municipal wastewater, specific methanogenic activity, inoculum.

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1 Introduction

Nicaragua is located in the centre of the Central American isthmus and it is the largest country in Central America, figure 1. The country occupies an area of approximately 130,000 square kilometres; i.e. it is 0.43 times the area of the Italy. According to the census of 1995, the estimated population is about five millions inhabitants with an annual growth of 3%. The extent of wastewater treatment is still very low. This situation is illustrated by the fact that only 12 % of the cities that posses a system of potable water have a municipal wastewater system. The city of Managua, which has 20% of the population of Nicaragua, has a sanitary sewage system, but it does not have a wastewater treatment facility.

Figure 1: Location of Nicaragua.

There are 24 small and medium municipal wastewater treatment plants attended by the National Institute of Aqueducts and Sewage (ENACAL), most of them are stabilisation lagoons, septic tanks, Imhoff tanks and some of anaerobic upflow filters. The wastewater treatment plants are located in small- and intermediate-size cities.

The object of this study is the evaluation of sludge from three anaerobic municipal wastewater treatment plants due to the low effluent quality that has been observed in the facilities. Two of selected plants work with Imhoff tank and one with septic tank followed by anaerobic upflow filter. It is known in general sense; the effluent quality is a function of treatment system design, maintenance and the composition of the influent. However, concerning to the septic and Imhoff tanks, there is limiting information relating the effluent quality to activity of biomass existing in the system.

Septic and Imhoff tanks are based on anaerobic processes for removing the organic matter. The biochemistry and microbiology of anaerobic digestion is a complex biogenic process involving a number of microbial populations, often linked by the individual substrates and product specificities.

Analysis of the activity of individual trophic groups involved in the overall process of methanogenesis has, up to now, mainly focused on determination of the activity of the acetotrophic methanogen population of digester sludge. This focus on acetoclastic methanogens has been largely dictated by the crucial role played by this population in methane evolution in digesters. To date, no internationally accepted test protocols have been delineated for determination of the specific activity of individual trophic populations in anaerobic digester biomass samples (Colleran and Pender [1]).

Due to the limited substrate range of methanogens, full mineralization under methanogenic conditions of the wide variety of organic constituents present in a waste or wastewater requires the coordinated and sequential involvement of the various bacterial trophic groups. As shown in figure 2, the conversion of complex substrate ingredients proceeds via the formation of numerous intermediate products.

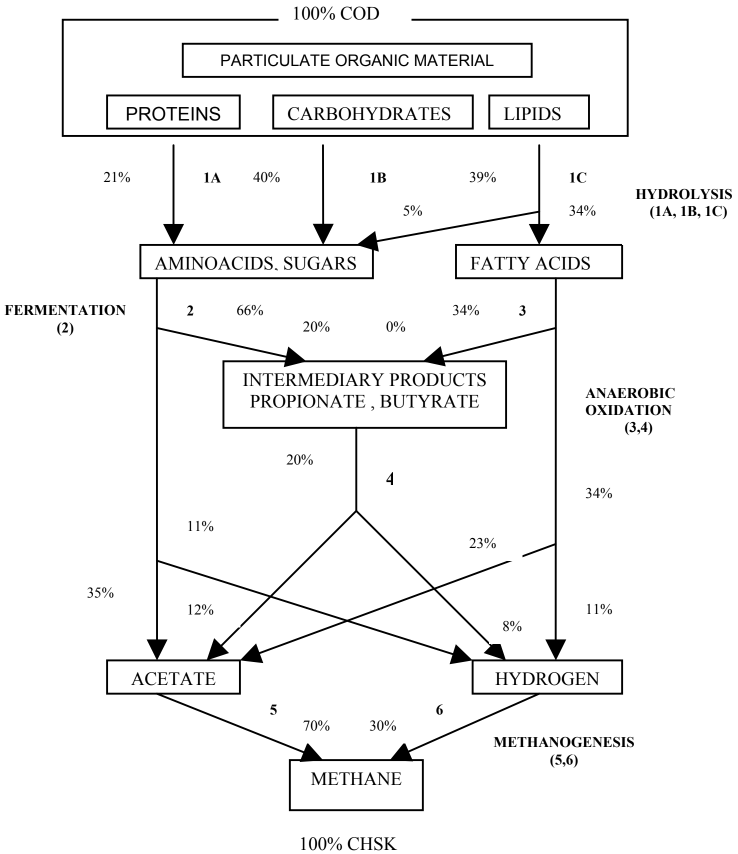

Figure 2: Schematic diagram of carbon flow conversion in anaerobic digesters (Hutñan *et al* [2]).

The first group of organisms which plays an important role in anaerobic digestion are the hydrolytic fermentative (acidogenic) bacteria. These bacteria hydrolyze the complex polymer substrate to organic acids, alcohols, sugar, hydrogen, and carbon dioxide. The second group is hydrogen producing and acetogenic organisms, which convert the fermentation products of the previous step (hydrolysis and acidogenesis) into acetate and carbon dioxide. Acetic and propionic acids are the source of about 85% methane through the whole treatment of a complex residue (Soto *et al* [3]). The third group is the methanogens, which convert simple compounds as acetic acid, methanol, and carbon dioxide plus hydrogen into methane (Hutñan *et al* [2]).

In examining the anaerobic degradation process of complex organic substrates six distinct steps can be identified:

1) Hydrolysis of organic polymers.
2) Fermentation of amino acids and sugars to hydrogen, acetate and short-chain VFA (volatile fatty acids) and alcohols.
3) Anaerobic oxidation of long-chain fatty acids and alcohols.
4) Anaerobic oxidation of intermediary products such as volatile acids (except acetate).
5) Conversion of acetate into methane by acetotrophic organisms.
6) Conversion of hydrogen into methane by hydrogenotrophic organisms (carbon dioxide reduction).

The accurate determination of the methane production is of primary interest, especially when small size reactor is used.

In general, anaerobic processes are determined by four main steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Hutñan *et al* [2]). The measurement of the methanogenic activity of anaerobic sludge is important in order to classify its potential in converting soluble substrate to methane and carbon dioxide.

A variety of test procedures have been developed over the years in order to screen for the susceptibility of organic chemicals to anaerobic methanogenic biodegradation. Test methods developed to determine the anaerobic biodegradability of wastewater organic have, typically, been utilized and modified to allow evaluation of the specific activity of individual trophic groups and to determine the potential toxicity of organic/inorganic compounds towards the populations involved (Colleran and Pender [1])

The interest in and application of each of them are quite different: while a methanogenic activity measurement (overall activity) allows the selection of an adapted sludge to be used as inoculum in an anaerobic digester, an individual activity determination makes possible the detection of potential unbalanced situation among the different bacterial species and the determination of the relative significance of the different steps of the process.

Reviews of experimental conditions may be found elsewhere (Soto *et al* [3], Field *et al* [4], and Jawed and Tare [5]). Some of these methods are quite simple; the sample volume, inoculum size, substrate content and concentration are determined according with the aims of the work.

This paper presents the application of a methanogenic activity test procedure to evaluate samples of sludge from different wastewater treatment plants to select one of them as inoculum for seeding a brewery wastewater treatment plant.

2 Methods

Three municipal wastewater treatment plants were object of this study: septic tank from Ocotal city and Imhoff tanks from La Paz Centro and from El Viejo. The wastewater and sludge were analysed according to the purposes of the study. The wastewater was characterized for nutrients, heavy metals and the organic load. Chemical analyses were conducted on both influent and the effluent of the system. The temperature, pH, BOD, Total Nitrogen, Total phosphorous, Cd, Cu, Cr, Pb and Zn were determined according to standard methods (American Public Health Association [6]).

The laboratory experiments with sludge were divided in two parts. Firstly, fresh sludge was analysed for density, temperature, redox potential (RP), pH, Volatile Suspended Solids (VSS) and Total Suspended Solids (TSS), understanding that TSS is the portion of total solid retained by the filter and VSS is the volatile fraction of TSS after ignition. VSS is commonly used as an indicator of the amount of biomass present in the sample. The measurement of biomass in terms of volatile solids concentration has the disadvantage that its estimation includes not only living microorganisms, but inert mass; e.g. exopolymers, organic matter absorbed in flocks or biofilms (Arnaiz *et al* [7]). However, because of its simplicity the method is still widely used.

Secondly, the methanogenic activity test was realized. The procedure described by Jawed and Tare [5] as proposed by Soto *et al* [3], was modified to suit the requirements of this study. The experimental set-up is shown in figure 3.

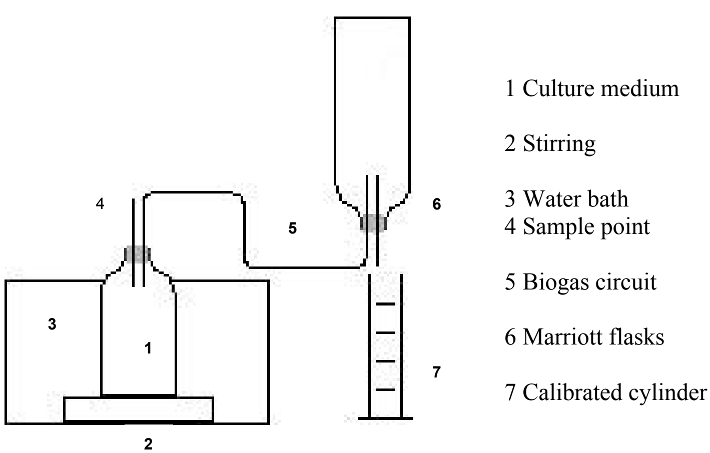

Figure 3: Schematic of methanogenic activity test set-up.

The system consisted of six flasks submerged in a water bath with temperature controller. The test was conducted at 35±1˚C. Continuous mixing of the sludge in the digestion flask was maintained using magnetic stirrers.

A known amount of sludge (corresponding to a concentration of VSS = 1.5 g/l) was transferred into a 500 ml serum bottle. The substrate solution was prepared with distilled water; and oxygen was purged with nitrogen gas. An appropriate quantity of substrate was used so as to obtain initial COD levels of about 2.5 g/l. Nutrients were not added in order to restrict growth of biomass during the test period and for the sake of reproducibility of the experiments (Soto *et al* [3]). The tests were made in triplicate. The substrate used to estimate the maximum methanogenic activity consisted of acetic acid. $NaHCO_3$ was added to maintain pH in the normal range of operation, 6.8-7.2. Direct methane gas production was measured using Mariotte flask filled with an NaOH solution, the method is based on the liquid displacement. COD and VSS were determined by the Standard Methods [6].

The methane activity was expressed as g CH_4-COD· g^{-1} VSS. d^{-1} and calculated from methane production rate (dV_{CH4}/dt), and it is expressed as followed:

$$(Ac_m)=(dV_{CH4}/dt)/(X_o V_R f) \qquad (1)$$

where V_{CH4} is the cumulative volume of methane production, X_o the initial concentration of substrate, V_R useful volume of the reactor and f a conversion factor which represents the amount the COD per unit volume of methane.

3 Results and discussion

The average composition of wastewater from mentioned wastewater treatment plants is given the table 1.

It could be observed that the wastewater was able to provide sufficient nutrients for anaerobic microorganisms; the nutrients component in the relation COD:N:P of 100:5:1 was even outgoing the required level, typical characteristic for the municipal wastewater. The influent presented a neutral pH. The levels of water quality parameters still do meet the effluent standards of the local authority in terms of BOD presents in the effluent (less than 100 mg BOD/l). The reduction of the BOD in the studied plants is in the range of 75-85% approximately. The concentration of all heavy metals analysed in this study was inferior that threshold of inhibitory effect on heterotrophic organisms (Tchobanoglous [8]). However, it was observed during the last years the constant fluctuations in the effluent characteristics with a clear tendency of increasing the pollutants in the treated water.

This information indicates proper conditions for a good development of biomass and there are no reasons to expect that the decrease of quality of treated water is due to the composition of influent.

Table 1: Characteristics of the wastewater analyzed in the experiments.

	Ocotal		El Viejo		La Paz Centro	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
Ph	7.09	6.88	7.3	7.0	7.4	6.97
Temperature, °C	26.8	27.1	28.5	28.7	26.7	26.5
BOD (mg/l)	294.0	57.5	206.0	45.25	593.75	89.38
Nitrogen (mg/l)	29.5	20.4	21.8	18.32	41.67	33.31
Phosphorous (mg/l)	19.8	15.4	18.51	12.01	48.33	24.73
	Influent	Toxic level*	Influent	Toxic level	Influent	Toxic level
Cd (mg/l)	Nd**	1.0	Nd*	1.0	0.00015	1.0
Cu (mg/l)	0.037	1.0	0.0042	1.0	0.0050	1.0
Cr (mg/l)***	0.0043	10.0	0.0038	10.0	0.0030	10.0
Pb (mg/l)	<0.005	0.1	<0.005	0.1	0.0072	0.1
Zn (mg/l)	0.0057	1.0	0.0301	1.0	0.0404	1.0

* Tchobanoglous [8] ** Non detectable level *** Total chromium

The characteristics of the sludge used in the experiments are shown in table 2. The average values of three replicas and standard deviation were calculated for all parameters and reflect no significant variability.

A Specific methanogenic activity of sludge (SMA) in the Imhoff tanks are relatively close and oscillate between 0.16-0.28 g CH4-COD/g VSS/day, and in the septic tank is 0.09 g CH4-COD/g VSS/day. These values agree with the methanogenic activity found in the literature for septic tanks (0.02-0.1 g CH_4-COD/g VSS/day) (Bello-Mendoza [9], Wasser *et al* [10]). The highest methanogenic activity measured during the test was 0.28g CH_4-COD/g VSS/day in the sludge of Imhoff tank in The Viejo city.

Table 2: Characteristics of the sludge used in the experiments.

	Ocotal Septic tank	El Viejo Imhoff tank	La Paz Centro Imhoff tank
Ph	7.42	7.13	7.24
Temperature, °C	27	28	28
TSS, g/l	107.77	87.64	90.35
VSS,g/l	42.67	30.59	20.25
VSS/TSS	0.39	0.35	0.22
Density,g/l	1.06	1.04	1.03
RP, mV	-210.3	-218.1	-194.8
SMA, g COD/g$^-$SSV.d	0.09	0.28	0.16

It is notable that the SMA of the sludge extracted from Imhoff tank is higher than from the septic tank, reaching the values comparable with those obtained for methanogenic activity of sludge from UASB reactor. According to the consulted literature, in some cases this range is between 0.25-0.9 g CH4-COD/g VSS/day (Hutñan [2], Akarsubasi [11], Cronin [12]) in hot climate and could be so low as 0.11 g CH4-COD/g VSS/day at moderate temperatures (Seghezzo *et al* [13]). The SMA showed a clear trend to decrease at increasing VSS concentration, as suggested Seghezzo *et al* [13], VSS could be a quick indicator of the sludge activity. The ratio VSS/TSS was less than 0.5 in all measurements, an indication of a stabilized sludge.

4 Conclusion

The results indicate that treated wastewater did not have any impediment to proper development of microorganisms; no presence of toxics and enough essential nutrients were detected. This fact is reflected in an acceptable value of the SMA of the sludge evaluated in this study. The reduction of BOD removal in the plant observed during the last years dose not relate to the composition of wastewater.

The sludge from the Imhoff tank of El Viejo city could be proposed as a seed for a local brewery wastewater treatment plant because presented the highest SMA and a relatively well relation VSS/TSS.

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