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Assessment of a Fixed Biomass Anaerobic Reactor for the Treatment of Vinasse

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ABSTRACT: The Cane alcohol vinasse assessment on the removal efficiency of a fixed biomass anaerobic reactor (FBAR) was evaluated. Crude vinasse was used to feed the reactor. The FBAR was operated with organic load rate (OLR) of 0.5, 1, 3 and 6 gCOD/L/d. Removal efficiencies of 85, 82, 75 and 66 per cent were observed respectively. The FBA reactor presented an excellent removal of organic matter, however, when more than OLR of 3 gCOD/L/d, an unexpected behavior began, it reduced its capacity. The average biogas production was 1.925, 2.613, 5.653 and 8.290 L for OLR of 0.5, 1, 3 and 6 gCOD/L/d respectively. The methane content in biogas was 56, 79, 89 and 82 per cent, in each OLR tested. Methane production was 1.070 L for an OLR 0.5 gCOD/L/d, 2.070 L on an OLR of 1 gCOD/L/d, 5.046 L with OLR of 3 gCOD/L/d and 6.800 L to OLR of 6 gCOD/L/d. Methane performance was used as monitoring parameter, this parameter gives information of the value between the catabolic activity (methane production) and the anabolic activity (bio-film production). The average YCH4, values were 0.304, 0.302, 0.306 and 0.205 LCH4/gCODremoved, respectively. The thermoplastic support inoculated in the FBA reactor and fed with crude vinasse, acted as a filter, plus getting good results in removal of chemical oxygen demand (COD), but because of the size and height of the filling, the methane evacuation stopped.

Keywords: Vinasse, Biogas, Distillery, Anaerobic digestion, Alcohol, FBA reactor

INTRODUCTION

The alcohol industry is the most important agro-industry for economic development in Mexico. However, the alcohol industry has been identified as one of the industries that consume large amounts of water and energy, and produces numerous organic pollutants, causing serious pollution problems. All distilleries, produce waste water commonly known as "vinasse", which is equivalent to 10-15 times the volume of alcohol produced (Patel et al., 1996). According to the origin of the raw material and the fermentation/distillation process used to obtain alcohol, is the high content of COD, total nitrogen, and total phosphorus effluent among other parameters. The arrangement of the stillage in the environment is dangerous and has a high potential for contamination. The highly colored components of vinasse reduce the penetration of sunlight into rivers, lakes or ponds which in turn decrease both the photosynthetic activity and dissolve oxygen concentration affecting aquatic life. According to Pant & Adholeya (2007) the brown color of the vinasse is due to phenolic compounds (humic acids and tannins) from the raw material, called melanoidins generated by the Maillard reaction of sugars (carbohydrates) and proteins (amino groups). Sharma et al., (2007) indicate that the unpleasant odor of the vinasse is due to the presence of skatole, indole and other sulphur compounds, which are not effectively decomposed by yeast during distillation.

Many technologies have been explored to reduce the pollutant load of distillery effluent, some biological treatments are among them, could be either aerobic or anaerobic, but in most cases a combination of both are used. The physicochemical methods such as adsorption, coagulation-flocculation, and oxidation processes have also been applied to the treatment of distillery effluent (Pant & Adholeya, 2007). Herein a system of fixed biomass, in which microorganisms attach

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to an inert medium, which can be any of the known support medium and used in biological filters is discussed. The wastewater passes through this medium, either in upflow or downflow. In the whole setting, a substantial percentage of the biomass occurs in suspended flocs and is retained in the voids of the inert medium. This reactor operates generally unused waste water recirculation, which gives rise to a flow-piston system, although production of gas tends to agitate the flow through the rising gas bubbles. Recirculation can be used to control the thickness of the bio-film to a certain degree, or to overcome the problems raised by the pH or toxic. (Hernández,1998). In this study the influence of OLR was assessed by removal efficiency

MATERIALS & METHODS

The FBA reactor (Fig. 1) is constructed of (Poly Vinyl Chloride) PVC material with a height of 1.15 meters, and 10.6 centimeters in diameter and working volume of 8.2 L. The reactor was fed with vinasse, by a peristaltic pump, the hydrodynamic conditions and the upward flow was maintained by using a peristaltic pump recirculation Masterflex® type. The reactor was operated in a warm room with controlled temperature of 30 °C, to maintain it in mesophilic conditions. On top of it a biogas collector is coupled. The gas passes through a device type Mariotte Flask containing 3N NaOH solution.

Corrugated plastic pipes, sectioned into 1 centimeter long were used as support material for the fixed biomass anaerobic reactor. 80 per cent of the filler has a diameter of ½ inch and 20 per cent of ¾ inch. The entire support weighed 0.928 g and the reactor was filled with this medium at a height of 80 centimeters. Such thermoplastic support has low density, high porosity and a high contact specific surface area of 450 m2 / m3 (Pérez et al., 1998) Then, 1L of anaerobic sludge was used to populate the support with the necessary bacteria to perform debugging. The sludge came from experimental biological treatment processes. The support medium was fed with urban waste water and vinasse, obtained from a local distillery. Inoculation time was about 1.5 months, achieving a moderate population. A solution of inorganic medium (Table 1) was added to the support medium to improve bacteria development The inorganic medium also provided a buffer for stabilizing a neutral pH during the experiment.

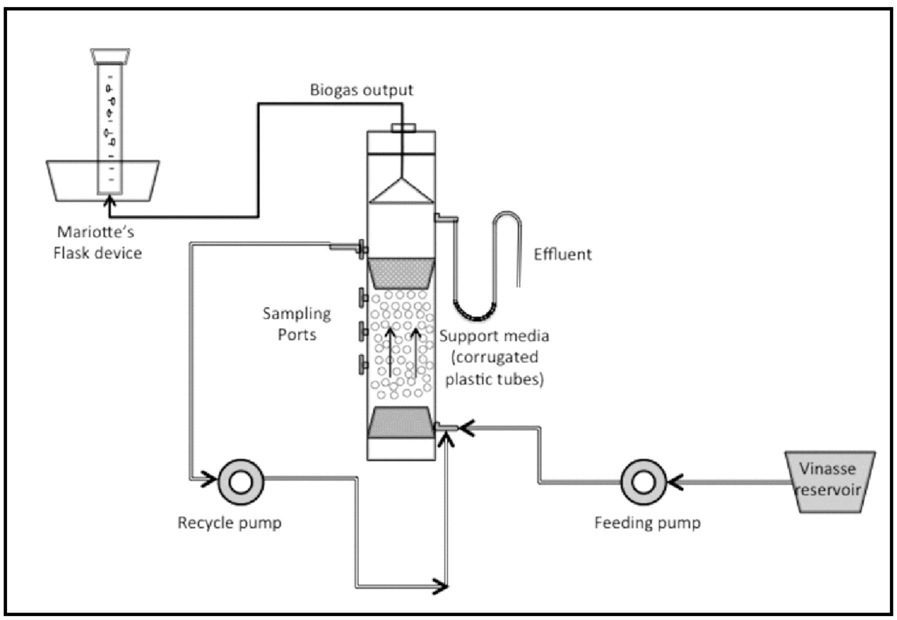

Fig. 1. Fixed Biomass Anaerobic Reactor

Table 1. Solution of modified inorganic médium

Modified Kawahara		Stock solution volume/100 ml reactor
KH_2PO4	4.05 g/l	15 ml Stock solution of KH_2PO_4
K_2HPO4	8.385 g/l	4 ml Stock solution of K_2HPO4
NH_4Cl	7.95 g/l	4 ml Stock solution of NH_4Cl
$CaCl_2$	1.125 g/l	4 ml Stock solution of $CaCl_2$
$MgCl_2.6H_2O$	1.0 g/l	4 ml Stock solution of $MgCl_2.6H_2O$
$FeSO_4.7H_2O$	5.6 g/l	4 ml Stock solution of $FeSO_4.7H_2O$

Note: Original solution of inorganic medium (Kawahara *et al.*,1999)

The vinasse used throughout the study comes from a local familiar distillery, which daily processes around 20,000 liters of alcohol from molasses. The production of vinasse is about 20 liters per liter of processed alcohol, i.e. 200 m3 per day. The gross vinasse is downloaded and processed in an anaerobic lagoon system. The vinasse was monthly sampled during the project; the average characterization of vinasse is summarized in Table 2. The reactor was operated in continuous mode, feeding the stillage with a peristaltic pump. The vinasse was manually neutralized before feeding the reactor, taking a pH 4-7 with 3N NaOH solution.

The experiment began with OLR 0.5 gCOD/L/d. Then gradually increased to OLR 6 gCOD/L/d, according to the experience of Sosa-Villalobos, et al., (2014), in the vinasse treatment with a UASB reactor. Operating conditions are summarized in Table 3.

The stabilization of the system was verified by analyzing the daily influent and effluent of the following parameters: CODtotal, CODsoluble, sulfate (SO42-), total solids (TS), volatile total solids (VTS), total suspended solids (TSS), volatile suspended solids (VSS), pH, temperature, biogas and CH4 produced. Samples of soluble compounds were centrifuged previously (6000 rpm for 30 minutes), for analytical determination. The followed procedures correspond to those indicated by Mexican Standards, and Standard Methods for the Analysis of Drinking and Waste Waters (APHA, 1995).

RESULTS & DISCUSSION

In Fig. 2, the evolution of the percentage of soluble COD removal versus time for each OLR tested is reported. The removal efficiency at OLR of 0.5 gCOD/L/d immediately filed stable values with an average of 85%.

When increasing the OLR to 1 gCOD/L/d high removal values, which were close to 95 per cent (about 67 days) were initially observed. The efficiency gradually decreased and stabilized at an average removal value of COD of 82 per cent, after passing approximately 50 days. When the OLR was increased to 3 gCOD/L/d, the same profile was observed, an initial removal increment and after 10 days of operation, an average soluble COD removal of 75 per cent was observed.

Rising OLR to 6 gCOD/L/d generated the same profile after 10 days of operation, an average removal of 66 per cent of the soluble COD. Apparently the use of a biofilm allows the microorganisms not to be dependent to OLR and thus achieve more high removals. The average biogas and methane production was 1.93 L and 1.07 L, respectively for an OLR 0.5 gCOD/L/d, the methane content in the biogas was 56 per cent. Values

Table 2. Vinasse characterization

Parameter	Average	Maximum	Minimum
pH	4.14	4.44	4.03
Conductivity (µs/cm)	21.17	29.80	7.73
Tot-COD(g/L)	128.63	217.71	57.59
Sol-COD(g/L)	108.48	156.07	36.13
TTS (g/L)	80.12	113.98	17.85
VTS (g/L)	58.11	81.67	11.81
TSS (g/L)	6.83	15.24	1.08
VSS (g/L)	5.42	11.78	0.96
N-Organic (g/L)	0.25	0.65	0.08
TKN(g/L)	0.28	0.69	0.12
N-NH4 (g/L)	0.03	0.05	0.003
Total phosphate (g/L)	0.08	0.15	0.01
Sulfates(g/L)	9.36	14.64	5.03

Table 3. Operating conditions of the fixed biomass anaerobic reactor with tested OLR

Parámetro	OLR (gCOD/L/d)			
	0.5	**1**	**3**	**6**
Upflow velocity (m/h)	0.4	0.4	0.4	0.4
Flow rate (L/d)	0.092	0.061	0.238	0.412
HRT (days)	89	135	34	20
Temperature (ºC)	35±2	35±2	35±2	35±2

of 2.61 and 2.07 L of biogas and methane were obtained with an OLR of 1 gCOD/L/d, respectively and a percentage CH4 of 79 per cent, in this condition the HRT was 135 days. Under the conditions of OLR of 3 gCOD/L/d, average values of biogas, methane and CH4 percentage of 5.65 L, 5.05 L and 89 per cent with an HRT of 34 days respectively were observed. In the last tested OLR of 6 gCOD/L/d, average values of biogas and methane 8.29 and 6.8 L respectively were presented. An 82 per cent of methane content in the biogas was also observed, this with a HRT of 20 days.

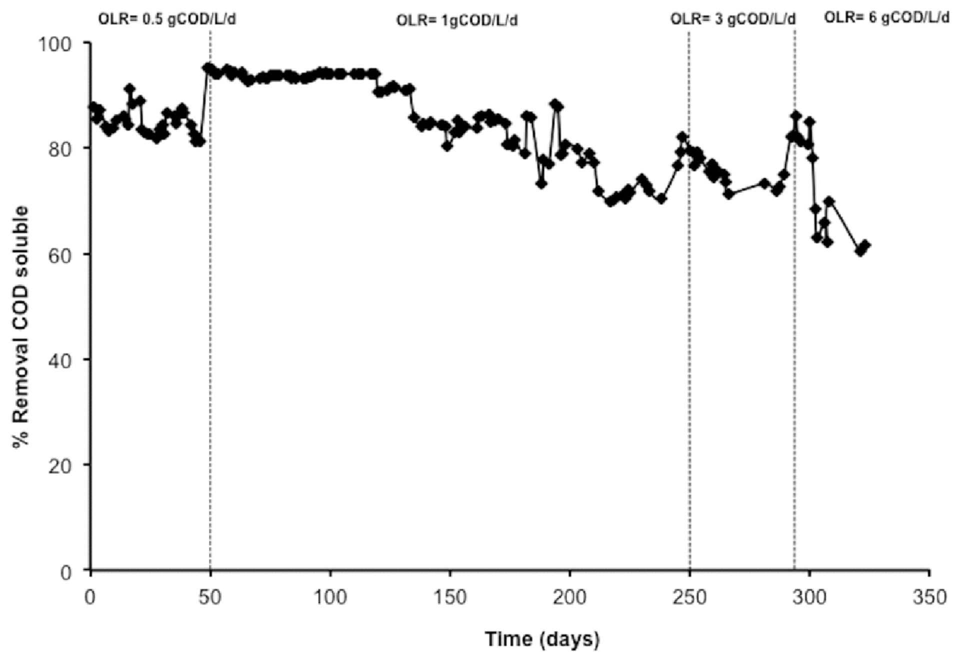

Fig. 2. Percentage of soluble COD removal versus OLR

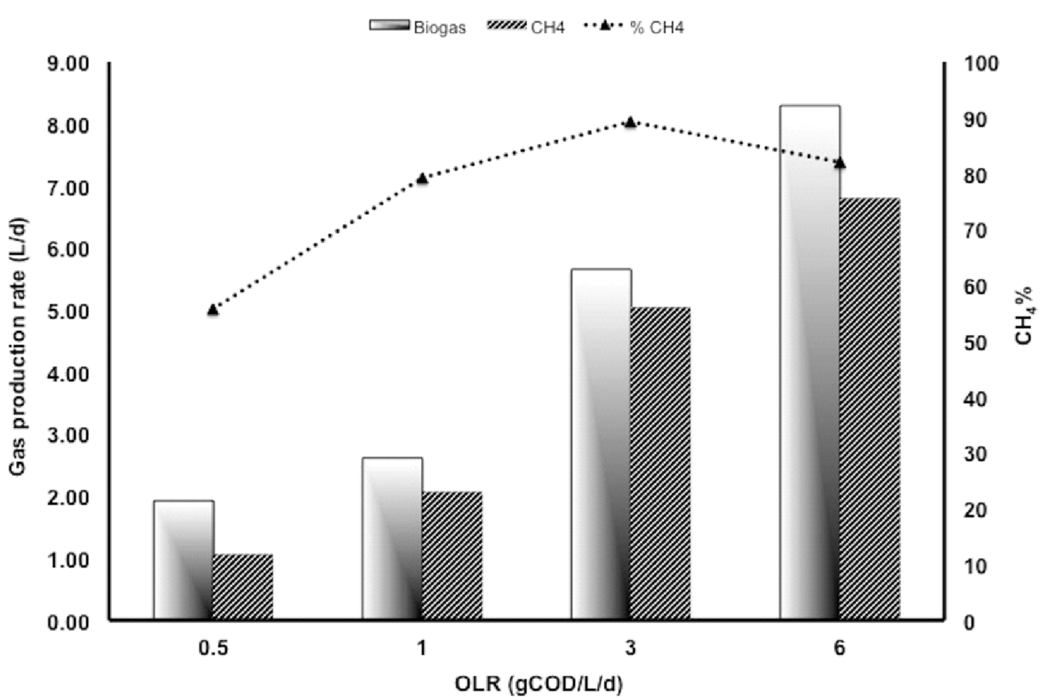

Fig. 3. CH4 and %CH4 biogas production versus OLR

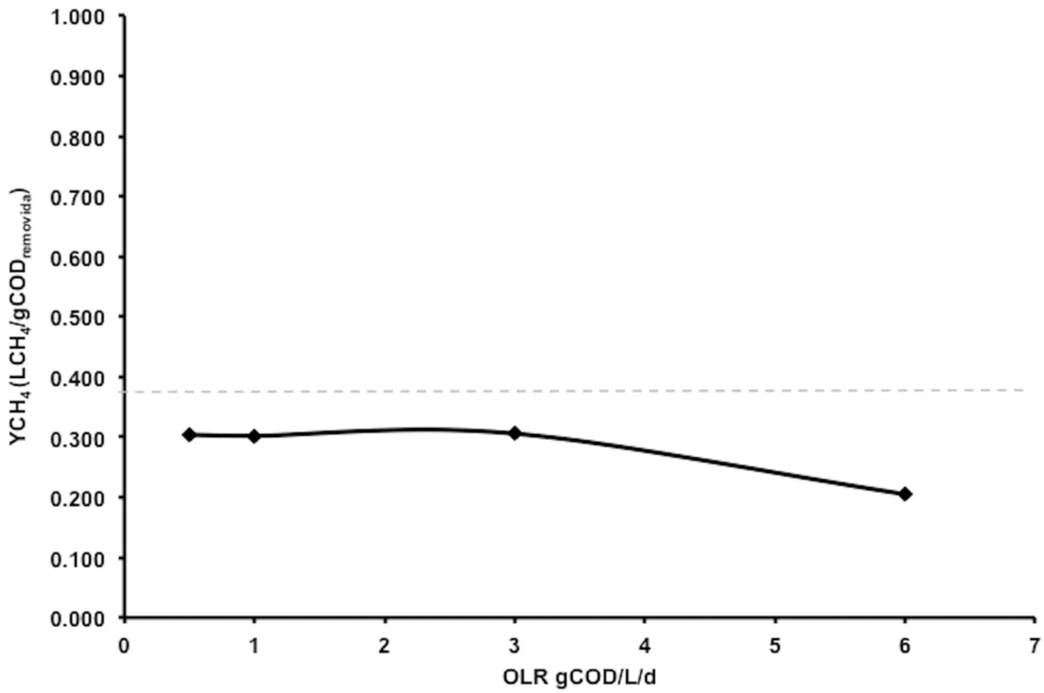

Fig. 4. Methane yield versus OLR

As defined by Michaud et al. (2005) the methane yield (YCH4) or the methane volumen produced per gram of removed COD can be interpreted as the balance between the flows of organic carbon to catabolism and anabolism in methanogenic ecosystems. At the beginning of the start-up period of the FBA reactor, the Y_{CH4} was very low indicating a significant anabolic activity of microorganisms to produce biofilm.

Upon reaching a steady state, the methane yield is constant and its value depends on the fraction of the biodegradable organic matter and the nature of the compounds (Alvarado, 2005). This means that the methane yield is constant when the anaerobic ecosystem uses carbon just for growth and maintenance. The evolution of methane yield is shown in Fig. 4. During OLR of 0.5 gCOD/L/d, average values of Y_{CH4} were observed of 0.304 L_{CH4}/ $gCOD_{removed}$

By increasing ORL of 1 and 3 gCOD/L/d, it reached an YCH4 average of 0.302 and 0.306 LCH4/ gCODremoved respectively. For ORL of 6 gCOD/L/d a lower methane yield with a value of 0.205 LCH4/ gCODremoved was observed. The FBA reactor was operated in a warm room at 30°C, allowing to calculate a theoretical YCH4 of 0.388 LCH4/gCODremoved. This parameter gives information of the value between the catabolic activity (methane production) and anabolic activity (bio-film production). When an OLR of 3 gCOD/ L/d, one YCH4 optimal of 0.306 LCH4/gCODremoved was reached, which can be interpreted that most of the organic matter was converted to methane, and a ratio of COD was used for biomass production. Indeed, the process of maturation of the biofilm requires organic matter for anabolism. On the other hand we could consider that when using a fixed support, there is no biomass release by abrasion. However, doubling the OLR to 6 gCOD/L/d, the volumen of biogas produced did not double and the YCH4 decreased, indicating a greater use of organic matter towards anabolism. We can assume that under these operating conditions (an increment of ORL of 6 gCOD/L/d), the recirculation flow as well as an intensive production of biogas generated hydrodynamic conditions that created an intensive biomass detachment and force the bio-film to shift their metabolism.

According to Michaud et al., (2002) each reduction of the methane perfomance, can be seen as a response of the biomass to physiological stress, it is observed when bacteria come into contact with the support medium or in periods of overloads. Furthermore. the methane yield as an indicator can provide information on the dynamic stages of the biofilm development during the start-up, and after the disturbances during operation of the reactor.

The following YCH4 results have been reported by various authors, using synthetic or mineral supports. It was obtained a YCH4 of 0.31 and 0.24 LCH4/ gCODremoved respectively, using corrugated plastic tubes and SIRAN pearls and the wastewater came from a wine distillery (Pérez et al., 1997). Treating wastewater of milk permeate (whey byproduct), and using polyehylene support called Bioflow 9® a YCH4 of 0.34 LCH4/gCODremoved was obtained. (Wang et al., 2009).

CONCLUSIONS

By using a biofilm, maximum removals of COD above 80 per cent were achieved. Apparently the recalcitrant COD fraction of the vinasse achieved to be processed by the biofilm attached to the support, although the total amount of biomass present in the FBA reactor was inferior. Regarding the use of a thermoplastic support, this also plays a filter role. However, given its dimensions and the filling height, it also slows down the evacuation of methane, generating much loss of biomass and indirectly affecting the efficiency of the anaerobic digestion.

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