Effect of the recycle on the two-phase anaerobic digestion process treating coffee wet wastewater

Yans Guardia-Puebla*, Suyén Rodríguez-Pérez**, Janet Jiménez-Hernández***, Víctor Sánchez-Girón****, Juan M. Morgan-Sagastume*****, Adalberto Noyola*****

* Departamento de Ciencias Técnicas, Universidad de Granma (UDG), Carretera Manzanillo, km 17 ½, Peralejo, Bayamo, CP 85100, Cuba. (E-mail: yguardiap@udg.co.cu)
** Centro de Estudios de Biotecnología Industrial (CEBI), Universidad de Oriente (UO), Patricio Lumumba s/n, Santiago de Cuba, CP 90500, Cuba. (E-mail: suyen@cebi.uo.edu.cu)
*** Centro de Estudios de Energía y Procesos Industriales, Universidad de Sancti Spíritus, Avda. de los Mártires, Nº 360, Sancti Spíritus, CP 60100, Cuba. (E-mail: janet@suss.co.cu)
**** Escuela Técnica Superior de Ingenieros Agrónomos (ETSIA), Universidad Politécnica de Madrid (UPM), Ciudad Universitaria, s/n, CP 28040 Madrid, Spain. (victor.sanchezgiron@upm.es)
*****Instituto de Ingeniería, Universidad Nacional Autónoma de México (UNAM). Circuito escolar s/n Edificio1, Ciudad Universitaria, Delegación Coyoacán, CP 04510 México D.F. Mexico. (E-mail: jmm@pumas.iingen.unam.mx; noyola@pumas.iingen.unam.mx)

Abstract
The present work shows the results of the anaerobic digestion assessment for the treatment of coffee wet wastewater. The effect on the anaerobic digestion of the two recycle rate, 0.4 and 1.0 in a two-phase system was evaluated. In the two-phase system with a recycle rate of 1.0, total and soluble COD removal efficiencies reaching values above 90%. The introduction of the recycle in the two-phase system decreased the concentration of total VFA, suggesting that the VFA degradation was stimulated. The presence of the acidogenic reactor in the two-phase system improved the stability of the anaerobic digestion process and increased the efficiency of methanogenic digester.

Keywords
Anaerobic digestion; coffee wet wastewater; two-phase system; recycle

1. INTRODUCTION

The anaerobic digestion is a fundamental process that combined with other appropriate methods, either aerobic or physical-chemical, can be a suitable and sustainable technology to treat waste in developing countries. In the conventional process, the forming-VFA microorganisms and forming-methane microorganisms stay together inside a reactor, where a delicate balance among those bacteria groups must exist, since both groups differ widely in physiological terms, nutritional needs, growth kinetic and sensitivity to the environmental conditions [1]. Ghosh and Pohland [2] were the first in suggesting the physical separation of the forming-acids and forming-methane microbial populations in two separated reactors where the optimal conditions for each microorganism group are established, improving, therefore, the stability and control of the anaerobic digestion process. The recycle of the effluent treated in the methanogenic reactor towards the acidogenic reactor is a method that facilitates the hydrolysis of the organic matter in the two-phase anaerobic digestion. Similarly, it improves the extraction conditions of the organic matter and, at the same time, the produced buffer capacity prevents the excessive acidification in the reactor [3]. This method provides the dilution of the polluting organic load to the anaerobic reactor and the reuse of the alkalinity produced in the process in the acidification reactor. On the other hand, as the pH of the affluent in this phase can be partially controlled there is a possibility of reducing the operational costs thanks to a decrease in the amount of extra alkalinity added to the system [4]. In consequence, the aim of this work was to assess the operation response of a two-phase anaerobic digestion system under recycle of part of the effluent of the methanogenic reactor towards the acidification reactor.

2. METHODS

2.1. Reactors

Two-phase anaerobic digestion system consisted of a first reactor for hydrolysis-acidification phase and a second reactor for acetogenesis-methanogenesis phase (Fig. 1). In this system, the first reactor was a glass cylindrical reactor, of 0.35 m of height and 0.076 m of diameter and nominal volume of 2.13 L. The second reactor was based on another glass cylinder of 0.43 m of height and 0.076 m of diameter and nominal volume of 2 L.

2.2. Experimental procedure

The inoculum used was granular sludge coming from an industrial scale UASB reactor that processed canned juice wastewaters having a volatile suspended solid (VSS) concentration of 73.5 g L^{-1}. The laboratory reactors were fed with coffee wet processing wastewater, located in Ixhuatlán community, Veracruz, Mexico. The composition of wastewater is shown in Table 1. As the coffee wet processing wastewater was acid its pH had to be adjusted using sodium bicarbonate ($NaHCO_3$). Hydrolytic-acidogenic phase reactor and the acetogenic-methanogenic phase reactor were inoculated, respectively, with 0.64 and 0.4 L of the granular sludge already mentioned. The characteristics of the different evaluation conditions are detailed in Table 2. The start-up lasted three weeks and then two recycle rates, 0.4 (Run1) and 1.0 (Run2), in a cycle of three weeks each one, were evaluated. With the aim of increasing the alkalinity available to deliver to the first reactor it was established an internal recycle rate of 0.2 in the second reactor.

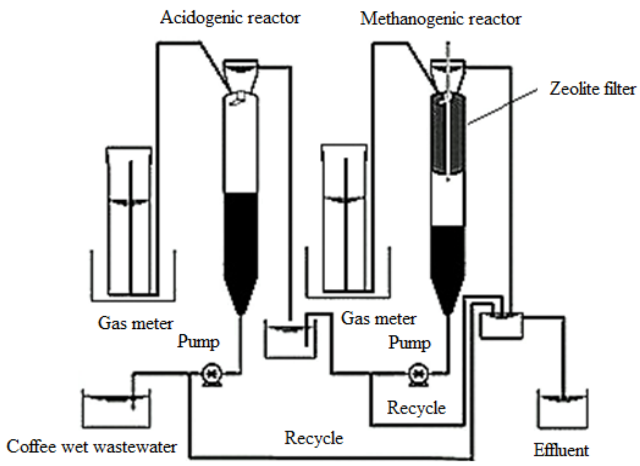

Fig. 1. Experimental setup of the two-phase system.

Table 1. Characteristics of the coffee wet wastewater.

Parameters	Wastewater
Total COD (mg L^{-1})	2545±142(60)
Soluble COD (mg L^{-1})	2302±175(60)
pH	3.79±0.21(60)
ST (mg L^{-1})	1228.5
TVS (mg L^{-1})	1141.6
SST (mg L^{-1})	315.7
SSV (mg L^{-1})	271.2

Table 2. Operating parameters of the two-phase system.

Systems		Parameters	Operation conditions	
			Run1	Run2
Two-phase	Acidogenic Reactor (AR)	HRT (h)	5.5	5.5
		Flow (L h^{-1})	0.39	0.39
		OLR (kgCOD m^{-3} d^{-1})	10.9±0.49(9)	10.4±0.73(9)
		Recycle rate	0.4	1.0
	Methanogenic Reactor (MR)	HRT (h)	16	16
		Flow (L h^{-1})	0.19	0.38
		OLR (kgCOD m^{-3} d^{-1})	2.3±0.2(9)	2.1±0.1(9)
		Recycle rate	0.2	0.2
	Overall conditions	Overall HRT (h)	21.5	21.5
		Overall OLR (kgCOD m^{-3} d^{-1})	4.2±0.2	5.7±0.4

2.3. Analytical methods

Total, volatile and suspended solids, pH and alkalinity were determined according to the Standard Methods [5]. The alpha index was calculated as the quotient of partial alkalinity at pH 5.75 and total alkalinity at pH 4.30. Total and soluble chemical oxygen demand (COD) analyses were carried out using a HACH COD reactor (digestion at 150ºC for 2 h) according to the closed reflux colorimetric method. Volatile Fatty Acids (VFA) were analyzed with a gas chromatograph (Chromatograph SRI Model 8610, with a flame detector, Zebron column, and Helium gas carrier to 206 kPa). The biogas production was daily quantified by displacement of the liquid column placed in each of the reactors gas meters. The methane concentration in biogas was measured by gas chromatography (Chromatograph Fisher Gas Partitioner Model 1200, equipped with a detector of thermal conductivity, double column Porapack Q and mesh molecular SA, with Helium gas carrier flow of 25 mL min^{-1}).

3. RESULTS AND DISCUSSION

3.1 Performance of two-phase anaerobic digestion system

3.1.1. Hydrolysis-acidogenesis phase

Figure 2a shows the evolution of the pH in the effluent of the acidogenic reactor. During the start-up stage, the system showed an average pH value in the effluent of 6.25±0.21, once the pH of the wastewater to be treated was adjusted to an initial value of 6.5. Because a pH of 6.0 was the objective to reach in the effluent of the acidogenic stage, the pH of the wastewater to treat was reduced during the Run1 assessment to values of 6.0 and 5.6 in two consecutive stages. When the recycle was induced, a larger hydraulic load having a pH close to 8 coming from second reactor enters to the first reactor, causing an eventual increase in H^+ concentration in this last reactor, that resulted in an increase of the alkalinity in the system [3]. In Run1 the recycle ratio was 0.4 and it rose up to 1.0 in Run2. For this reason two other pH drops to values of 5.5 and 5.4 were carried out in days 50 and 57, respectively. This pH decrease resulted in an effluent pH interval whose range was 5.80-6.13, and an average value of 6.06±1.17.

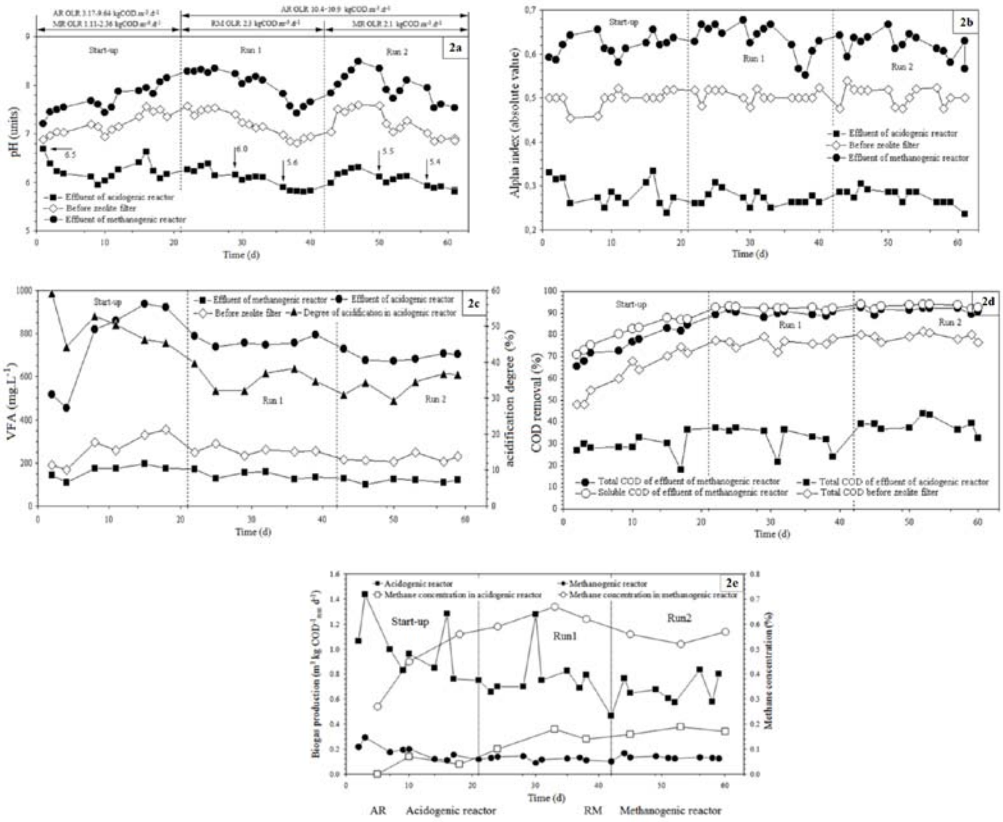

Fig. 3. Performance of the two-phase system: a) pH; b) Alpha index; c) VFA concentration; d) COD removal efficiency; e) Biogas production and methane concentration.

As it is observed in the Fig. 2b, the recycle did not have a significant effect in the alpha index. When all the data measured in Run 1 and Run 2 were considered, the alpha index mean value was 0.27±0.02, and0 the alkalinity mean value was 837 mg$CaCO_3$ L^{-1}. Such low alpha index and alkalinity mean values were expected since the purpose of the acidogenic phase is the VFA production. Therefore, the high concentrations of VFA in this reactor were responsible for the low mean values of those two variables [6, 7]. Figures 2c and 2d show the VFA concentrations and the COD removal efficiency behaviour in the effluent of the acidogenic reactor for the two recycle rates evaluated. The compounds that resulted in this second experiment with recycle were acetic acid (55-56%), propionic acid (34-35%) and butyric acid (9-11%), and their respective concentrations were 388-418 mg L^{-1}, 243-261 mg L^{-1} and 65-85 mg L^{-1}. On the other hand, the interval of the COD removal efficiency varied within the range of 32-38% for both conditions (Run1 and Run2), and the average acidification degree was 35±3%. Romli *et al.* [8] observed a similar situation and they reported that the increase of the recycle has the effect of diluting the VFA and the wastewater concentration to treat.

Biogas production and methane concentration are observed in the Fig. 2e. The biogas production and methane concentration achieved average values of 0.728±0.169 m^3 $kgCOD^{-1}_{rem}d^{-1}$ and 15±1.7%, respectively.

3.1.2. Acetogenic-methanogenic phase

Effluent pH values of the methanogenic reactor were observed in the interval of 7.68-8.03, with an average value of 7.9±0.3 (Figure 2a). This pH interval allows concluding that an appropriate performance of the methanogenic phase was achieved. Alpha index values were measured in a range of 0.55-0.68 (Figure 2b) and the total alkalinity mean value was 1231±93 mg$CaCO_3$ L^{-1}. The effluent recycle from the methanogenic reactor towards the acidogenic reactor reduced the sodium bicarbonate consumption required in the latter to increase the pH of the incoming wastewater. These results confirm that the recycle enables to decrease the operation costs in a two-phase anaerobic system, due to smaller alkalinity consumption. This observation agrees with what has been reported by other authors [9] [8]. Therefore, the effluent recycle allows decreasing the use of an alkaline substance, so it influences significantly in the operation cost of an anaerobic system.

Average acetic and propionic acid concentrations in the effluent were of 76±21 mg L^{-1} and 43±7 mg L^{-1}, respectively, whereas the butyric acid concentration was below the chromatograph detection limit. It was observed a tendency toward a decrease of the VFA concentration with the introduction of recycle (Fig. 2c), indicating that the anaerobic methanogenic microorganisms were stimulated by this factor. Recycle allows a better distribution of the anaerobic bacteria, a higher dispersion of the metabolic products produced, and a greater nutrient diffusion [10].

A beneficial effect of the recycle in terms of the organic polluting degradation was observed. The average total COD removal was 90±1%, while for the soluble COD removal it was 93.2±0.87% (Fig. 2d). Recycle also allowed the increase of the applied OLR in the anaerobic system in two phases. An increase of the OLR of up to 5.7 kgCOD m^{-3} d^{-1} did not affect the performance of the process, maintaining high degradation efficiencies of the organic matter. The average total biogas production in the methanogenic reactor of the two-phase system was 0.129±0.017 m^3 $kgCOD^{-1}_{rem}$ d^{-1}(2e). In Run1, when a recycle rate of 0.4 in the acidogenic reactor was considered, the methane concentration in the biogas produced (2e) varied in an interval of 59-67%; whereas increasing the recycle rate to 1.0 in the same reactor, the methane concentration decreased to 52-59%; which indicated that the increase in the recycle rate decreased the methane concentration in the biogas. According to Romli *et al*. [8], an increase in the recycle rate eventually increases the CO_2 production in the biogas.

4. Conclusions

In the two-phase anaerobic digestion process treating coffee wet wastewater, recycle caused an alkalinity reutilization that resulted in a rise in the pH of the acidogenic reactor; however, the anaerobic methanogenic microorganisms in the next phase were stimulated by this factor because decrease the VFA concentration in the effluent, and total and soluble COD removal efficiency values above 90%. Recycle increased the OLR applied in the two-phase system without being affected the COD removal efficiency, but at the expense of a decrease in the concentration of methane in the biogas.

References

[1] M. Dareioti, S. Dokianakis, K. Stamatelatou, C. Zafiri, M. Kornaros, Biogas production from anaerobic co-digestion of agroindustrial wastewaters under mesophilic conditions in a two-stage process, *Desalination*, 248 (2009) 891-906.

[2] F. Pohland, S. Ghosh, Developments in anaerobic stabilization of organic wastes: The two-phase concept, *Envir. Letters*, 1 (1971) 255-266.

[3] O. Stabnikova, L. Xue-Yan, W. Jing-Yuan, Anaerobic digestion of food waste in a hybrid anaerobic solid-liquid system with leachate recirculation in an acidogenic reactor, *Biochem. Eng. J.*, 41 (2008) 198-201.

[4] B. Demirel, O. Yenigün, Two-phase anaerobic digestion processes: a review, *J. Chem. Technol. Biotechnol.*, 77 (2002) 743-755.

[5] APHA, Standard methods for examination of water and wastewater, Nineteenth ed. American Public Health Association, Washington D.C., USA., 1995.

[6] A. Pérez, P. Torres, Índices de alcalinidad para el control del tratamiento anaerobio de las aguas residuales fácilmente acidificables, *Ingeniería Sanitaria*, 10 (2008) 41-52.

[7] R. Leitão, A.v. Haandel, G. Zeeman, G. Lettinga, The effects of operational and environmental variations on anaerobic wastewater treatment system: A review, *Bioresour. Technol.*, 97 (2006) 1105-1118.

[8] M. Romli, P. Greenfield, P. Lee, Effect of recycle on a two-phase high-rate anaerobic wastewater treatment system, *Wat. Res.*, 28 (1994) 475-482.

[9] K. Kida, Y. Sonoda, Treatment of coffee waste by slurry-state anaerobic digestion, *J. Ferment. Bioeng.*, 69 (1992) 354-359.

[10] M. Gerardi, The Microbiology of Anaerobic Digesters, John Wiley & Sons, Inc. Hoboken, New Jersey, USA, 2003.