TOWARDS TO ANAEROBIC CO-DIGESTION OF OFMSW BASED ON THE ANALYSIS OF CHEESE WHEY AND MEAT WASTE ON TWO TYPES OF SLUDGE

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ABSTRACT

Anaerobic co-digestion (AcoD), of two substrates, cheese whey (CW) and meat waste (MW) has developed as an improvement to anaerobic digestion (AD) of Organic Fraction Municipal Solid Wates (OFMSW) due to its synergistic effects and higher biogas yield. However, the process start-up is a bottleneck for the spreading of AcoD based on CW and meet. Considering this background, the aim of this study was to assess anaerobic co-digestion of OFMSW based on the analysis of CW and MW on two types of sludge with the purpose of increasing biogas production. Significant differences in biogas production can be observed for the different initial conditions tested. The remaining volatile fatty acids (VFA) after anaerobic digestion in all cases with suspended sludge remains between 8 and 22 g kgVS^{-1}. At the end of co-digestion, (90-day) high biogas yield of 383 NL kgVS^{-1} was observed at R2; this co-digestion, with nitrogen addition, which is in keeping with that of current production systems endorses meat waste as a promising substrate for production of biogas. For the two tested sludge, reactors with granular sludge produced more biogas than suspended sludge.

Keywords: Co-digestion, anaerobic digestion, OFMSW, cheese whey and meat waste.

INTRODUCTION

In order to increase supply through alternative sources of energy and minimize impacts on the environment, the Mexican Law for the Use of Renewable Energy and the Financing of Energy Transition (LAERFTE, 2008) establishes that, by 2024, participation of non-fossil sources in electricity generation will be 35% in Mexico.

Currently in Mexico, 52.4% of Urban Solid Waste (RSU) corresponds to the Organic Fraction of Urban Solid Waste (OFMSW) and more than 10 thousand tons of food are wasted per year, representing up to 37% of country production (SEDESOL, 2014, FAO, 2015).

The increase in consumption of all types of materials by the society has led to a significant increase in the production and complexity of waste (Teixeira et al., 2014), becoming an environmental problem that can be achieved a social welfare linked to the ability of the environment to absorb the impacts produced (Moestedt et al., 2016). Energy recovery is a form of waste management, which exploits the energy potential of the waste, and reduces the amount of material that is sent to final disposal (Beevi et al., 2015). A treatment route, which combines efforts for energy and waste management, is the anaerobic digestion applied to organic waste to generate biogas (Cuetos et al., 2008; Galbe et al., 2012). Almeida et al. (2011) reported that anaerobic digestion is a serie of procedures and specific reactions involving at least eleven microbial groups (Figure 1), where their metabolic capacity and interactions have not yet been fully understood. Shen et al. (20013) have concluded that a single-phase digestion achieved more methane production than two-phase; however, two-phase digestion may have more stable operation.

The strategies for intermediary processes (detailed in the bibliography) are diverse; the main aspects that have been studied have to do with the temperature conditions, the application of pretreatments and the use of different configurations of the process.

Anaerobic digestion is not very widespread in the cheese whey industry, because it is a very fragmented sector with large and small producers. In Mexico, CW is a type of waste with great potential of use in the process of anaerobic codigestión, since it can produce up to 9 kg of cheese whey per one kilogram of cheese produced, this waste generation represent 35 % of national waste (FAO, 2015), as mentioned by Venetsaneas et al. (2009), CW consists of lactose (45–50 g/L), lipids (4– 5 g/L), soluble proteins (6–8 g/L), and mineral salts (8–10% of dried extract). For the treatment of cheese whey, biological treatments are preferably applied before it is poured into soils and rivers, which is why conventional and unconventional processes arise. Conventional processes purify the wastewater and not the serum itself. The isolation of undesirable currents is the first stage of unconventional processes, which seeks to use the industrial waste to obtain various fermentation products.

Cattle meat is the third more consumed worldwide. In Mexico City the production of cattle meat is 1.91 million (carcass weight), which plays an important role in the economy (FIRA, 2017). As a result of the growth of this processing industry, there is also a significant 37% increase in the generation of cattle meat waste (FAO, 2015), whereas annual rate production has increased 0.3 per cent, waste mitigation techniques have lagged behind the ever increasing accumulation of waste (Harris and McCabe, 2015). An alternative for the treatment of such waste is anaerobic digestion that could provide a rich source of proteins.

In the last decade, several configurations of reactors have been evaluated and proposed for the improvement of biogas from organic waste (Koch et al., 2015; Fitamo et al., 2016). Anaerobic codigestión is a promising strategy for the generation of value-added products from waste, allowing to take advantage of the complementarity of the waste composition to unify its management, produce energy and stabilize its process. Some researchers (Shen et al., 2013; Rodriguez-Chiang et al., 2016; Xie et al., 2017) have argued that codigestion may provide larger treatment efficacy as well as process stability in relation to single-substrate digestion. Although co-digestion has been successful through the use of sewage sludge and various organic wastes, such as food waste (Koch et al., 2015; Xie et al., 2017) slaughter house waste (Moestedt et al., 2016) or garden waste (Fitamo et al., 2015), among others reported in many recent studies, several key aspects of the process of anaerobic codigestión remain vaguely understood. In particular, about the synergistic effect of codigestion on anaerobic behavior and the associated mechanisms responsible for such effect (Rodriguez-Chiang et al., 2016).

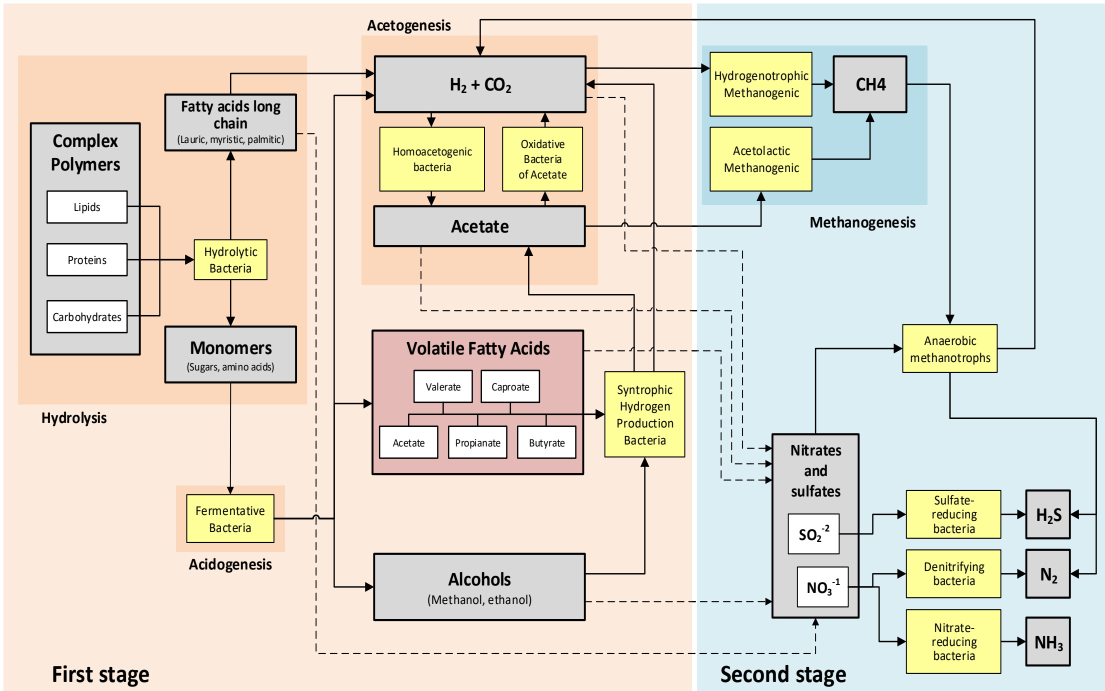

Figure 1 Degradation pathways by which microorganisms break down biodegradable material in the absence of oxygen

METHOD

Anaerobic codigestions of OFMSW was conducted to investigate whether the mixture of cheese whey and meat waste improve and brings more stability to the processes with a considerable increase in the production of biogas along with two types of inoculum, granular and suspended sludge, in batch assays. The experiment was carried out for a period of ninety (90) days, in a two stage process, where basically the first stage is the anaerobic digestion of OFMSW with suspended and granular sludge separately, in batch assays at 35°C, and the second stage was assessing the maximum biogas potential of the co-substrates (cheese whey and meat waste), setting up a biochemical methane potential (BMP) test at 35°C using the Bioprocess Control System.

Origin of substrates and seed sludge

The OFMSW sample was obtained from the Cuautitlán Izcalli wholesale market, Estado de Mexico, sampling was performed using the quartet method, based on and in accordance with the NMX-AA-015-1985 standard. A representative sample was homogenized, divided and stored in sealed bags of approx. 1kg each, and subsequent storage at -20 ° C until use. At the lab, one part of the OFMSW was defrosted at room temperature (22 °C) and further blended to smaller pieces to prevent clogging.

The meat waste was taken from a local market in Mexico City, and the cheese whey was obtained from a farm in the Southeast of the city of Oaxaca.

The granular sludge was collected from a UASB reactor from a beer company located in Mexico City. Suspended sludge was obtained from a FES Iztacala Pilot Plant, Estado de Mexico, treating OFMSW. Both seeds sludge were incubated in batch for 10 days, so that degrade the adsorbed substrate. The sludge granules were liquefied in an industrial blender afterwards; to wash and concentrate, samples were centrifuged at a rotational speed of 4000 rpm for 30 minutes.

Analytical methods

The reactors were sampled once being shaken vigorously to ensure complete homogenization of the medium and prior to be sealed with rubber stoppers. All analyses were performed in duplicate for the characterization of OFMSW, cheese whey and meat waste; elemental analysis (dry base), volatile solids (VS), chemical oxygen demand (COD) were analyzed (using fresh material) according to standard procedures (APHA, 1992). Throughout the experiment, biogas volume was measured by Bioprocess Control system. The detailed protocols for the determination of VFA by titration were followed with the reference (DiLallo and Albertson 1961) from the acid alkalinity were based on the premise that 80 per cent of the organic acid titration is between pH 4 and pH 7.

Batch experiments

The organic fraction of municipal solid waste (OFMSW) was prepared for two conditions, these conditions included the inoculum to substrate (I/S) ratio and cosubstrates (cheese whey and meat waste). Duplicate digestions were conducted in 0.5 L glass reactors (0.4 L working volume) with sample ports to allow gas to be collected during the experiment. All reactors were kept in a water bath at 35 °C (±0.5 °C) and continuously mixed to minimize mass transfer limitations. Table 1 presents the initial adjustments. Anaerobic conditions in the reactors were established by flushing the headspace with nitrogen gas for 3 min. Each reactor was seeded with a different volume of granular and suspended sludge separately at time zero of the experiment with 12 g VS and 15 g VS OFMSW respectably. The reactors were started under similar operational conditions. The reactor samples were taken once a week to measure pH, alkalinity, α factor, Buffer Index (BI), AI / AP, VFA.

Table 1 Operational conditions and results in different stages

Seed sludge	Initial conditions	Reactor	21 days anaerobic monodigestion*		90 days anaerobic codigestion*	
			VFA (g L^{-1})	Biogas production (NL $kgVS^{-1}$)	VFA (g L^{-1})	Biogas production (NL $kgVS^{-1}$)
Granular	OFMSW+CW	R1	3.4	113	2.7	140
	OFMSW+MW	R2	7.9	132	1.0	383
	OFMSW	R3	1.0	45	0.7	115
Suspended	OFMSW+ CW	R4	9.7	81	3.9	107
	OFMSW+MW	R5	10.9	101	4.3	105
	OFMSW	R6	1.3	6.8	0.7	27

* The data are the average values of the samples obtained during stable operation

RESULTS

Characteristics of the substrate

The characterization of the substrates and sludge (wet matter), in terms of pH, TS and VS contents are summarized in Table 2. The chemical and physical characterization indicated that the OFMSW had a TS content of 130 g/kg, the VS was 72% TS in line with the literature (Elbeshbishy, et al., 2012, Cabbai et al., 20013, Beevi et al.,2015, Ponsá et al.,2011), however, this comparison dependent on each experiment conditions. The seeded pH was low (pH of 3.67) due the high presence of volatile fatty acids (VFA). Following the fermentation, the pH increased as consequences of the VFA degradation as exhibited in Table 3.

Table 2 Characteristics of OFMSW (mean ± standard deviation of two replicates)

Parameter	Unit	OFMSW	CW	MW	Granular sludge	Suspended sludge
pH		5.05 ± 0.14	3.67 ± 0.14	7.15 ± 0.14	6.71 ± 0.12	6.5 ± 0.13
Humidity	%	86 ± 0.14	94 ± 0.14	50 ± 0.14	92 ± 0.15	90 ± 0.16
COD	gO_2/kg	50 ± 1.3	72 ± 1.3	73 ± 1.3	47 ± 0.3	72 ± 0.7
TS	g/kg	130 ± 5.6	64 ± 5.6	531 ± 5.6	61 ± 1.3	96 ± 0.1
VS	g/kg	125 ± 17	54 ± 17	522 ± 17	61 ± 0.9	96 ± 1.3
NH_4-N	g/kg	0.2 ± 0.01	0.3 ± 0.01	0.5 ± 0.01	- -	- -
Nitrogen*	g/g	2 ± 0.14	2 ± 0.14	9 ± 0.14	- -	- -
Carbon*	g/g	44 ± 1.3	36 ± 1.3	68 ± 1.3	- -	- -
Hydrogen*	g/g	5 ± 5.6	6 ± 5.6	9 ± 5.6	- -	- -
Carbohydrates	g/kg	118 ± 17	18 ± 17	4.1 ± 17	- -	- -
Lipids	g/kg	39 ± 0.14	1.6 ± 0.14	72 ± 0.14	- -	- -
Proteins	g/kg	34 ± 0.14	11 ± 0.14	155 ± 0.14	- -	- -
Lignin	g/kg	30 ± 1.3	- -	- -	- -	- -
Cellulose	g/kg	47 ± 5.6	- -	- -	- -	- -
Hemicellulose	g/kg	12 ± 17	- -	- -	- -	- -

Preliminary setup

In this work two types of sludge were used as inoculum, previously the experiment begins, both were stored at room temperature for one week to reduce its organic content (data not shown). It was also determined substrate concentrations and inoculum to substrate (I/S) ratio (VS basis), for CW and MW were required ≥ 2.5 g VS kg-1 and as reported by Labatut et al. (2011) a minimum I/S ratio of 0.5 was needed to ensure process start-up.

The reported biogas production was based on the detail levels of the normalization procedure and corrected assumed temperature and pressure of 22 °C, 1 atm and dry gas.

Reactors behavior during hydrolysis and acidification

The degradation products are observed in Figure 2, the remove of TS and VS were increased in all reactors seeded by a suspended sludge enhancing the anaerobic biodegradation of solid materials, however this type of behavior did not favor the biogas production. Reactors seeded by a granular sludge have a representative degradation; the highest and lowest VS degradation values of 52.8 % and 19.4 % were obtained with R1 and R3 respectably.

As presented in Table 3, removal efficiencies during anaerobic codigestion, the highest removal both were, from reactors working with CW (granular sludge 70.4 % and suspended sludge 75.1% was observed), which can be attributed to the synergistic effects (Xie et al., 2017); meanwhile suspended sludge with MW 48.2 % and OFMSW 60.7 % was reached, which was slightly higher COD removal than that from granular sludge (44.2% and 53.4 % respectively). Based on the results of this work it can be assumed that, regardless of the substrate assessed, the type of inoculum has an influence in the COD removal, being attributed as the optimum to suspended sludge; however incomprehensible that it seems suspended sludge reached a lower production of biogas (Figure 4) and contradicting result have been reported by Pereira et al. (2002), being thus a subject that still has yet to be explored to draw any definitive conclusions and a reliable mean.

Table 3 Physical and biochemical characteristics of the reactors

Reactor	**RT**	**pH**	**TS (g/ kg)**	**TS removed (%)**	**VS (g/ kg)**	**VS removed (%)**	**COD (gO2/kg)**	**COD removed (%)**

R1	Initial	8.3	102	47.5	84	51.1	71	70.4
	Final	6.7	53.5		41		21	
R2	Initial	8.3	104	52.8	98	61.2	70	44.2
	Final	6.8	49		38		39	
R3	Initial	8.1	77	19.4	61	29.5	73	53.4
	Final	6.3	62		43		34	
R4	Initial	8.2	73	63.0	63	71.4	77	75.3
	Final	6	27		18		19	
R5	Initial	8.3	86	68.6	80	76.2	58	48.2
	Final	5.8	27		19		30	
R6	Initial	8	104	81.7	96	90.6	28	60.7
	Final	6.7	19		9		11	

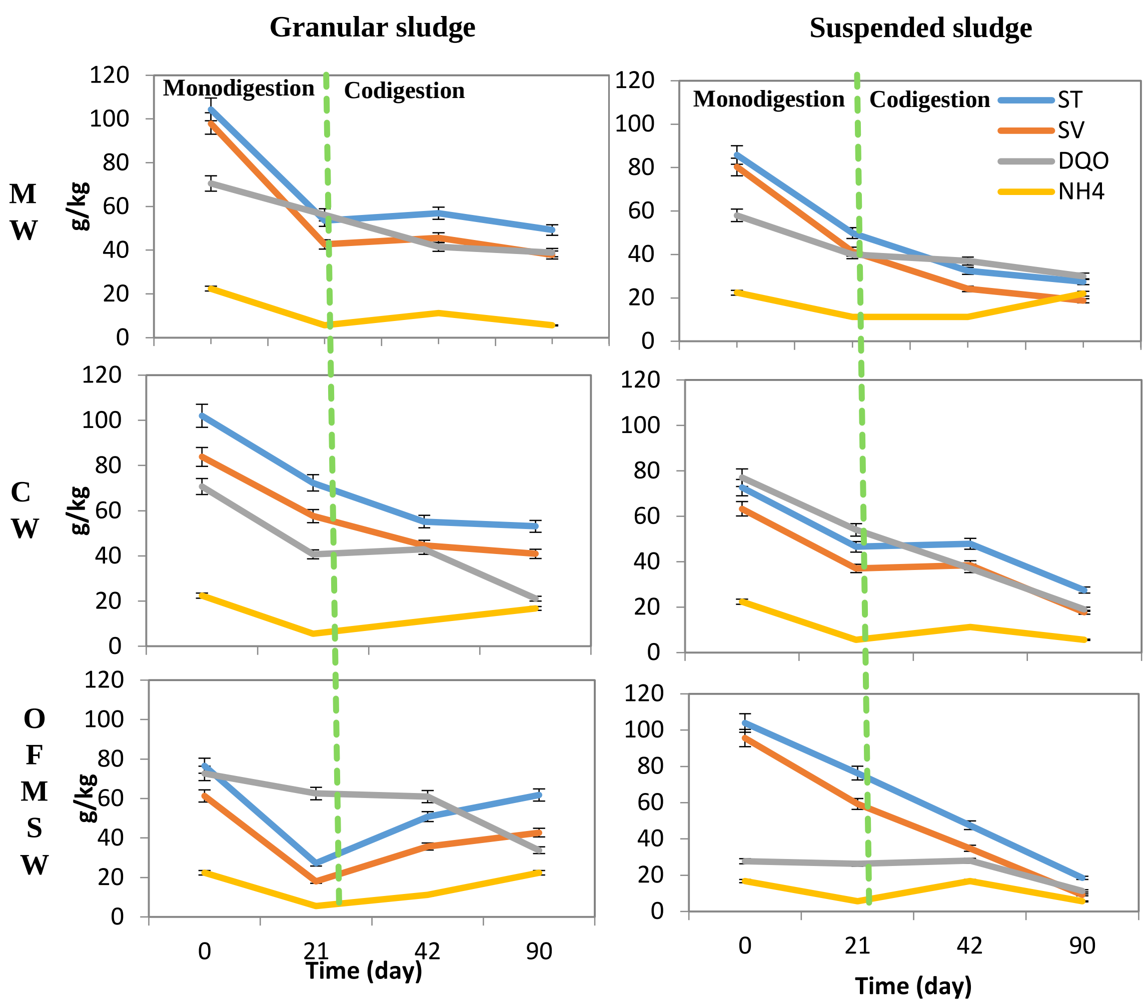

Figure 2 Key parameter of substrate mixture and corresponding seeded sludge from mono-digestion and co-digestion (MW=Meat Waste, CW= Cheese Whey, OFMSW= Organic Fraction Municipal Solid Waste); Error bar shows the standard deviation of two replicate experiments.

Cumulative biogas production

During the first stage, all reactors showed a successful startup. Significant differences in biogas production can be observed for the different initial conditions tested. Figure 3 shows the results by day 90, R2 reached a plateau of biogas production at 383 L $kgVS^{-1}$ and supported quite well with the production reported by Labatut et al. (2011). Cuetos, et al. (2008), found that treating OFMSW in codigestion with lipid and protein waste contributed to a significant increase in the daily biogas yield. However in this work, treating a high lipid waste (CW) was complex and led to the accumulation of VFA (Table 1).

Most of the methane production curves present a two-stage behavior: assays with a granular sludge, from day 10 to day 21, methane production decreases and then, from approximately day 25, methane production increases again to reach a maximum after day 27 for CW and day 35 OFMSW afterwards both kept steadily producing methane until day 90, however this behavior is completely diverse for MW due it is possible to observe two peaks of increase in its production of biogas this at day 37 that apparently remains constant although this production continues increasing until completing a maximum at day 90.

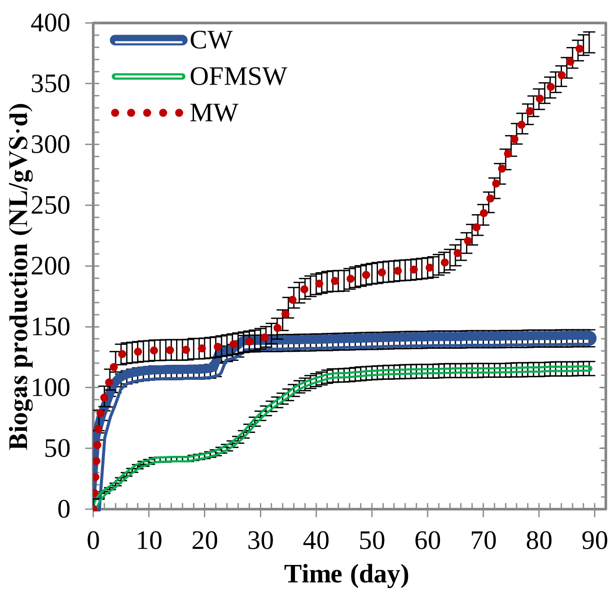

Figure 2. Daily variation of biogas production under BPM test at 35°C, granular sludge.

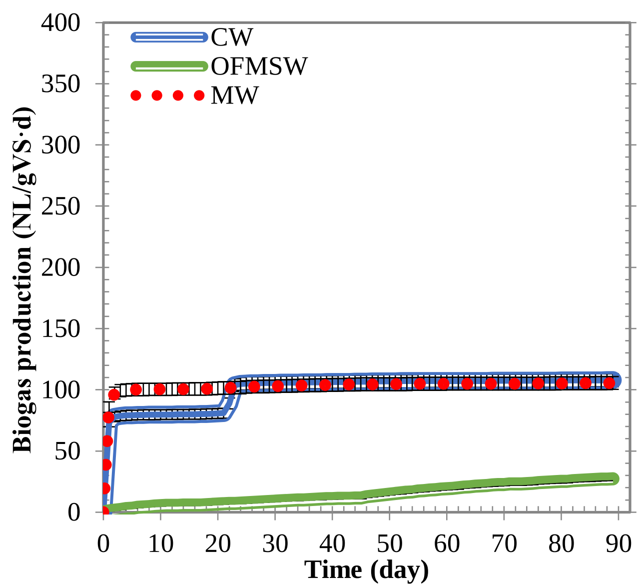

Figure 3. Process performance on suspended sludge and daily quantity of biogas production

These results indicate how important it is to consider composition and characteristics of OFMSW to estimate methane production rates during anaerobic codigestion and as was pointed out by Labatut et al. (2010) regardless of the prediction the amount of final products in anaerobic digestion, its factuality will depend on the knowledge of the substrate composition and its biodegradable fraction

CONCLUSIONS

The highest concentration of VFA at the end of the first stage (45-day) was R1, and thereafter due to the accumulation decreased the biogas production. At the end of co-digestion, (90-day) high biogas yield of 383 NL $kgVS^{-1}$was observed at R2; co-digestion of mixtures of meat waste with OFMSW allows higher production of biogas. Which lead us to conclude that the highest production of biogas was from reactors operated with granular sludge.

The conclusions of this study apply to lab-scale batch operations, therefore, a further improvement of the seeded sludge is deemed required to increase the rate of either CW or MW in codigestion with OFMSW.

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REFERENCES

Almeida, A., Nafarrate, R., Alvarado, A., Cervantes, O., Luevanos, O.R. Balagurusamy, N., 2011. Expresión genética en la digestión anaerobia: un paso adelante en la comprensión de las interacciones tróficas de esta biotecnología. Revista Científica de la Universidad Autónoma de Coahuila [revista en internet], 3(6). (In Spanish).

APHA. , 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed., American Public Health Association, Washington, USA.

Cabbai, V., Ballico, M., Aneggi, E., Goi, D. 2013. BMP tests of source selected OFMSW to evaluate anaerobic codigestion with sewage sludge. Waste management, 33(7), 1626-1632.

Cuetos, M. J., Gómez, X., Otero, M., Morán, A. 2008. Anaerobic digestion of solid slaughterhouse waste (SHW) at laboratory scale: influence of co-digestion with the organic fraction of municipal solid waste (OFMSW). *Biochemical Engineering Journal*, **40**(1), 99-106.

Elbeshbishy, E., Nakhla, G., Hafez, H. 2012. Biochemical methane potential (BMP) of food waste and primary sludge: influence of inoculum pre-incubation and inoculum source. Bioresource technology, 110, 18-25.

FAO (Food and Agriculture Organization/World Health Organization), 2015. Food Losses and waste in Latin America and the Caribbean. Expert Consultation. Bulletin 2.

FIRA (Fideicomisos Instituidos en Relación con la Agricultura), 2017. Panorama agroalimentario: Carne de bovino 2017 (in Spanish).

Fitamo, T., Boldrin, A., Boe, K., Angelidaki, I. Scheutz, C., 2016. Co-digestion of food and garden waste with mixed sludge from wastewater treatment in continuously stirred tank reactors. Bioresource technology, 206, pp.245-254.

Galbe, M., Zacchi, G. 2012. Pretreatment: The key to efficient utilization of lignocellulosic materials. Biomass and Bioenergy, 46, 70-78.

Harris, P.W., McCabe, B.K., 2015. Review of pre-treatments used in anaerobic digestion and their potential application in high-fat cattle slaughterhouse wastewater. Applied Energy, 155, pp.560-575.

IEA. 2013. An example of successful centralized co-digestion in Denmark, Bioenergy Task 37. Energy from Biogas.

Koch, K., Helmreich, B. Drewes, J.E., 2015. Co-digestion of food waste in municipal wastewater treatment plants: effect of different mixtures on methane yield and hydrolysis rate constant. Applied Energy, 137, pp.250-255.

Labatut, R.A., Angenent, L.T. Scott, N.R., 2011. Biochemical methane potential and biodegradability of complex organic substrates. Bioresource technology, 102(3), pp.2255-2264.

Ley para el Aprovechamiento de las Energías Renovables y el Financiamiento de la Transición Energética (LAERFTE). Palacio Legislativo de San Lázaro, martes 28 de octubre de 2008. Secretaría de Servicios Parlamentarios. Dirección General de Servicios de Documentación, Información y Análisis México (in Spanish).

Moestedt, J., Nordell, E., Yekta, S. S., Lundgren, J., Marti, M., Sundberg, C., Björn, A. 2016. Effects of trace element addition on process stability during anaerobic co-digestion of OFMSW and slaughterhouse waste. Waste Management, 47, 11-20.

Mottet, A., François, E., Latrille, E., Steyer, J. P., Déléris, S., Vedrenne, F., Carrère, H. 2010. Estimating anaerobic biodegradability indicators for waste activated sludge. *Chemical Engineering Journal*, **160**(2), 488-496.

Norma Mexicana (NMX-AA-015-1985). Protección al ambiente - Contaminación del Suelo -Residuos Sólidos Municipales - Muestreo - Método de Cuarteo. Modificada de acuerdo al Decreto publicado en el Diario Oficial de la Federación de fecha 6 de Noviembre de 1992 (in Spanish).

Pereira, M.A., Pires, O.C., Mota, M. Alves, M.M., 2002. Anaerobic degradation of oleic acid by suspended and granular sludge: identification of palmitic acid as a key intermediate. Water Science and Technology, 45(10), pp.139-144.

Ponsá, S., Gea, T., & Sánchez, A. (2011). Anaerobic co-digestion of the organic fraction of municipal solid waste with several pure organic co-substrates. Biosystems engineering, 108(4), 352-360.

Raposo, F., De la Rubia, M. A., Fernández-Cegrí, V., Borja, R. 2012. Anaerobic digestion of solid organic substrates in batch mode: an overview relating to methane yields and experimental procedures. *Renewable and Sustainable Energy Reviews*, **16**(1), 861-877.

Rodriguez-Chiang, L., Llorca, J. Dahl, O., 2016. Anaerobic co-digestion of acetate-rich with lignin-rich wastewater and the effect of hydrotalcite addition. Bioresource Technology, 218, pp.84-91.

Schievano, A., D'Imporzano, G., Malagutti, L., Fragali, E., Ruboni, G., Adani, F. 2010. Evaluating inhibition conditions in high-solids anaerobic digestion of organic fraction of municipal solid waste. *Bioresource Technology*, **101**(14), 5728-5732.

Shen, F., Yuan, H., Pang, Y., Chen, S., Zhu, B., Zou, D., Liu, Y., Ma, J., Yu, L. Li, X., 2013. Performances of anaerobic co-digestion of fruit & vegetable waste (FVW) and food waste (FW): Single-phase vs. two-phase. Bioresource technology, 144, pp.80-85.

SEDESOL (Secretaria de Desarrollo Social), 2014. El Medio Ambiente en México 2013-2014. Dirección General de Equipamiento e Infraestructura en Zonas Urbano-Marginadas (in Spanish).

Speece, R.E. Anaerobic Biotechnology and Odor/Corrosion Control for Municipalities and Industries. Archae Press, Nashville, TN; 2008.

Teixeira, S., Monteiro, E., Silva, V., Rouboa, A. 2014. Prospective application of municipal solid wastes for energy production in Portugal. Energy Policy, 71, 159-168.

Venetsaneas N, Antonopoulou G, Stamatelatou K, Kornaros M, Lyberatos G. 2009. Using cheese whey for hydrogen and methane generation in a two-stage continuous process with alternative pH controlling approaches. Bioresource technology, 100(15), pp.3713-3717.

Xie, S., Wickham, R. Nghiem, L.D., 2017. Synergistic effect from anaerobic co-digestion of sewage sludge and organic wastes. International Biodeterioration & Biodegradation, 116, pp.191-197.