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Anaerobic digestion in two stages of primary and secondary sludge anaerobic reactors with flow up

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Abstract: A train sludge treatment based on a new configuration and design of tubular glass UASB reactors upflow jacket, drawing 10 L volume and working volume of 8.6 L of mixtures of primary sludge (PS) were studied and secondary sludge (SS) in two stages. The first hydrolysis-acidogenesis in a mesophilic reactor (35±3ºC) without controlling pH, agitation, recirculation or pre concentrated sludge. The results showed that the reactor served as the settler-reactor, coming to have concentrations of 15 to 56 g TSS/L promoting solids retention time (SRT) 11 to 34 d. A first order kinetics in the destruction of solid, a value of the hydrolysis constant (k) of 0.0681d^{-1} at a hydraulic retention time (HRT) of 1 d, 12.5 d SRT, organic load (Bv) of 14.2 kg VSS/$m^{3}\cdot$d by 29 % and methane production rate of 0.009$L_{CH4}/L_R\cdot$d. In a second thermophilic stage (methanogenic phase) to 55±1ºC, also acted as the reactor-settler reactor and observed a correlation between the solids concentration of the reactor, the HRT, the SRT of the destruction of solid, and organic load supplied with suspensions given 1.8 to 9.4 g TSS/L in the feed concentrations of 6.5 was reached 32.8 g TSS/L have SRT allowing 7 to 22.9 d. And there is the further destruction of solids with SRT 7.4 d to 66% at organic loads (Bv) of 3.5 kgVSS/$m^{3}\cdot$d of 55% to 7.2 kgVSS/$m^{3}\cdot$d, SRT of 15.2 d with Q_{CH4} speeds of 0.005 and 0.09 $L_{CH4}/L_R\cdot$d. However, the value of k_4 confirmed its slowness in converting CH_4 VFA.

Keywords: Anaerobic, digestion, destruction of solids, sludge, reaction rate.

INTRODUCTION

During the process of wastewater treatment, sludge is generated with a small concentration of TSS and high load primary biodegradable. Sludges that are dark gray with a dry weight of the primary solids (PS) of around 50% of total solids generated in the activated sludge process, containing from 2 to 7% TSS and a water content of 95 to 97%[1]. Presents high easily biodegradable organic matter comprises proteins, carbohydrates and lipids to be hydrolyzed resulting in a reduction of volatile solids and increased chemical oxygen demand in the soluble phase (COD_S) with the consequent formation of soluble organic compounds which fermentation results in the formation of volatile fatty acids (VFA) short chain as acetic, propionic, butyric and isobutyric necessary for nutrient removal in biological processes[2]. And sludges side as aggregates composed of bacteria and exopolymer substances (EPS), which are immobilized almost all extracellular enzymes[3] (Yu, 2003). Addition of multivalent cations, such as silicates, iron oxide and calcium phosphate[4]. The EPS molecules are produced by the metabolism of the bacteria, those substances are 80 to 90% of the organic fraction of the SS and the rest are cells containing 44 to 55% protein, 30 to 33 % humic acids and 10% carbohydrates[5]. And containing de oxyribonucleic acid (DNA) varying between 2 and 15% of the content of the sludge EPS[6]. EPS percentages depend on the biomass and solids retention time in the reactor and the characteristics of the waste water containing 0.5 to 1.5% of TSS and consisting of 99% water. The suspended solids (ss) of the SS consist of suspended volatile solids (VSS), representing between 60 and 85% SS and at the same time represents the organic matter, while the suspended solids fixed (SSF), represent the inorganic material. The VSS are comprised between 30 and 54% proteins, between 7.7 and 12% fat and 9 to 22% carbohydrate[7]. The composition and production of the SS depends on the degree of secondary treatment; organic load (Bv), solids residence time (SRT), temperature and nature of the shock. As a byproduct of waste water treatment, containing pathogens and parasites[8] microorganisms. Moeller and Ferat[9] confirmed the presence of high amounts of the genus *Salmonella* with doubling times of 23 minutes to *Salmonella* typhi and 150 minutes to *Salmonella pollorus*. With survival times 2 months in wastewater and up to 8 months in soil. Besides Shigella, pathogenic protozoa man as G. lamblia and E. histolytic and more persistent parasites such as Ascaris lumbricoides and Strongyloides, the first viable periods for 22 months in shallow and deep water, and 1 to 2 months in culture. Which in most cases are discharged into sewage systems or water bodies arranged in open dumps without any prior treatment creating problems of environmental pollution and health[10]. This practice is both a waste of its beneficial properties to agriculture, to take nutrients and organic matter inputs to the soil, or to improve their ability eroded soil moisture retention[11]. Currently, the sludge treatment processes to meet the requirements for the production of biosolids require several unit operations including the thickening may be by gravity, flotation, centrifugation and filtration to concentrate the slurry of 2 to 8% TSS as anaerobic digesters are usually designed for a working concentration of 4 to 7% of TSS.

Anaerobic Digestion: Anaerobic digestion of complex organic materials has been described as a sequential multistep process of hydrolysis, acidogenesis, acetogenesis and methanogenesis[12]. However, the hydrolysis of complex organic matter into simpler particles is considered limiting step rate anaerobic digestion (AD), but can also be an inhibition by high solids loading, and consequently of excess particulate substrates. Hydrolysis of organic polymers is carried out by extracellular enzymes (hydrolases). Enzymatic steps in parallel with cellulases, proteases and lipases determine the degree of hydrolysis of carbohydrates, proteins and lipids. During the degradation of monosaccharides, amino acids and fatty acids, long chain hydrolysis products such as volatile fatty acids (acetate, butyrate, propionate, lactate and H_2 are formed as precursors for the production of methane. Stage of acidogenic followed by hydrolysis step is usually faster pace. However, for efficient production of methane is important to have a balance in the degree of reaction of the different steps involved during the organic complex matter. The kinetics anaerobic digestion is influenced by many factors which include: temperature and hydraulic retention time is decisive in the percentage of organic matter stabilized and destruction of solid High rates of hydrolysis are achieved with a good inoculum[13]. the degree of hydrolysis depends on the concentration of biomass and its metabolic activity are: 1) hydrolysis of complex particulate organic material, 2) Fermentation of sugars and amino acids, 3) anaerobic oxidation of long chain fatty acids and alcohols, 4) anaerobic oxidation intermediates as short chain fatty acids, 5) Homoacetogénesis and 6) Methanogenic. The stabilization of the sludge is the result of the activity of a multiple sintrófico balance microorganism group. The first group of microorganisms converts the macromolecular organic material into simpler compounds such as sugars, fatty acids and long-chain amino acids. The solubilized compounds are converted by acidogenesis to hydrogen and carbon dioxide. In acidogenesis phase, fatty acids and long chain alcohols are converted into acetic acid and hydrogen. In the last stage of anaerobic digestion methanogenic bacteria produce methane from acetic acid, carbon dioxide and hydrogen. The activated sludge anaerobic degradation requires further conversion mechanisms as death and lysis of the cells viable for subsequent hydrolysis of organic material. Process efficiency can be influenced by the different kinetics of the different groups of bacteria involved. The kinetics of biological growth are based and two fundamental relationships: growth rate and substrate utilization rate. During anaerobic digestion rate limiting each step is related to the nature of the substrate, the configuration of the process, the temperature and solids loading[14]. The hydrolysis takes place slowly, depending on the particulate material introduced into the digester, which guarantees the entire process kinetics. Acidogenesis kinetics, is an order of magnitude greater than the kinetics of methanogenesis; disturbance can change the activity of methanogenic bacteria can therefore have a negative effect on the process efficiency. The wide range of values of the first order kinetic constant of hydrolysis in primary and secondary sludge can be explained by; 1) the different experimental conditions, 2) the biomass hidrolitrica different relationships to the substrate, and 3) the effect of global breakdown. Some results have been reported in the literature for the primary and secondary sludge alone (table 1) but not mixtures thereof.

Table 1: Kinetic coefficients in the literature for describing sludge hydrolysis.

Substrate	K(d^{-1})	TºC	References
Primary sludge	0.25	35	Siegrist y col., 2002
Primary sludge	0.40	55	
Primary sludge	0.169	35	Ferreriro y Soto. (2003)
Waste activated sludge	0.17	70	Bolzonella y col., 2007
Waste activated sludge	0.026-0.035	35	Tomei y col., 2008
Waste activated sludge	0.017-0.16	10-35	Feng y col., 2009
Waste activated sludge	0.12	35	Zhang y col., 2010
Waste activated sludge	0.18	55	
Waste activated sludge	0.10-0.40	50-65	Ge y col., 2011
Waste activated sludge	0.12-0.80	50-70	Ge y col., 2011

Justification: In this study was investigated if an anaerobic reactor mesophilic to 35ºC without pre concentrate sludge with upflow achieve their thickening and at the same time acting as a filter will allow the retention of solids, allowing solubilization of solids leaving mud predigested with certain percentage of solids in the second stage (methanogenic phase) where it is expected that the reactor of thermophilic upflow 55ºC lead to methane products acidogenesis.

Biosolids production: In Mexico NOM-004-SEMARNAT-2002 defines the quality of the biosolids for their use. With the stabilization seeks biochemically break the organic solids to be more stable (less pestiferous and less putrescible) and dewater, reducing the mass and volume of the slurry until solids do not react each other or to their environment and reasonably reducing the density pathogens that may be in direct infectious to humans, or in its most resistant forms (cysts and eggs) [15]. The stabilization depends on the degree of destruction of volatile organic fraction or solids, it is therefore necessary to subject the sludge to disinfection treatments, ensuring the elimination of pathogens and stability of organic matter putrescible to use biosolids on agricultural land and leverage their carbon content of organic matter, nitrogen and nutrients (Ca, Cd, Mo, Na, P, S, etc.). Bacteria to enter the soil, play an important role in the cycling of carbon, nitrogen and sulfur; because various microbial groups possess the ability to use different types of electron acceptors: nitrate, sulphate and carbonate during the degradation of organic pollutants in ecosystems oiled and biotransformation of heavy metals[16]. They also promote the conditioning of clay soils[17]. Liquid sludges coming from the primary and secondary treatment, contains from 1 to 6.5% nitrogen and 0.6 to 2.5% phosphorus. Digested by the action of dry air, nitrogen content is reduced to 2% and phosphorus by up to 1.5%. The organic matter varies from 40 to 80% dry matter (DM)[18]. Its application in agricultural soils in European countries represents 45 to 56% [19]. The methods used in the stabilization, is based on: biological reduction of the content of volatile matter, chemical oxidation of volatile matter, elevated pH, increased temperature, application of heat in order to disinfect or sterilize the sludge. The intensity and exposure times of sewage sludge to these mechanisms are crucial for efficient disinfection[20]. Pathogen reduction and stabilization of the biosolids is achieved by a combination of mechanisms: 1) elevated pH (>12) for a period of 72 hours and 2) elevated temperature (T>52ºC) for a period of 12 hours[21, 22].

The reactions of anaerobic digestion (AD), are expressed with a pattern of consecutive following first-order kinetics equations:

$$SS \xrightarrow{k_1} DS \xrightarrow{k_2} B^- \xrightarrow{k_3} CH_4$$

$$V_{SS} = k_1 SS \qquad (1)$$

$$V_{DS} = k_1 SS - k_2 S \qquad (2)$$

$$V_{B^-} = k_2 S - k_3 B^- \qquad (3)$$

$$V_{CH4} = k_3 B^- \qquad (4)$$

Where ki = reaction rate constant (d^{-1}), SS = suspended solids concentration (g/L) and DS = concentration of dissolved solids in the soluble phase (g/L), B = VFA produced (g/L) methane yV_{CH4} = (L/d).

Whose efficiency is evaluated based on the destruction of organic matter (VSS or COD), volume and composition of biogas produced. During startup, stabilization of anaerobic digester sludge influences the composition of the substrate, environmental and operational parameters, mineral nutrients among which carbon, nitrogen, phosphorus, and small amounts of sulfur, vitamins (riboflavin and vitamin B12), mineral elements as Na, K, Ca, Mg and Fe in very low concentrations, in addition to cobalt, nickel, molybdenum and selenium[14]. While the pH affects the enzymatic activity of the microorganisms by changes of state of the ionizable groups, which causes alteration of non ionizable system components such as the denaturation of enzyme protein structure. High pH promotes the formation of free ammonia methanogenic phase inhibitor which causes imbalance between the production and consumption of volatile fatty acids by accumulation of these acidifying the reactor and the alkaline levels affects acetoclásticas methanogenic bacteria[23]. During the AD, the buffering capacity is due to the presence of carbonates, in particular the ability of bicarbonate HCO_3 buffer. In the digester bicarbonates of calcium, magnesium and ammonium are substances acting as buffers to maintain the pH constant. A stable digester has a total[24] alkalinity of 2,000 to 5,000 mg/L. A criterion to determine whether the organic loading is proper the digester, is by the ratio **α** of alkalinity due to bicarbonate between total alkalinity. The VFA/alkalinity ratio is also indicative of stability; A lower ratio indicates[25] immediate failure 0.4. Meanwhile, toxicity and inhibition may occur due to high concentrations of heavy metals and alkaline earth metals, volatile fatty acids[26], ammonia nitrogen[27] and sulfides[28]. For addition, temperature plays an important role in the growth of the species in the growth rate increases with temperature to a maximum, from which it starts to decrease. Temperature increases generate two important effects on organisms[29] On one hand, the catalytic reaction (KCSF) is favored as I Arrhenius first proposed in 1889 to quantify the effect of temperature on the enzymatic hydrolysis capacity in sugar[30]. In sewage sludge, as the temperature increases, the bacterial growth and hydrolysis of solids occurs more rapidly according to the following equation for the enzymatic catalysis[31]:

$$k = Ae^{-Ea/RT} \qquad (5)$$

Where:

K is the rate constant or hydrolysis constant (d^{-1}).

A is the Arrhenius constant which takes into account the frequency and orientation of molecular collisions.

Ea is the minimum energy required to conduct the transformation (which is called the activation energy (J/mol).

R is the gas constant (J/kmol).

T is the absolute temperature in K.

With values of activation energy in biological systems 4-20 kcal/mol, measured at 25ºC. An increase of 10°C favors the activity of 1.2 to 3.0 times, but when exceeding the threshold of a certain temperature the irreversible damage of biomass components (proteins, nucleic acids and other cellular components) is favored, is affected constants chemical balance the alkalinity and pH causing precipitation or redissolution of inorganic compounds, changes in the composition of biogas VOCs solution such as ammonia and hydrogen sulfide. Therefore, the temperature should be controlled properly, it changes might affect the process of anaerobic digestion of solid[31, 32]. In mesophilic anaerobic digesters some operation problems are: low reduction VSS and slow rate of destruction of pathogenic microorganisms. In PS to TRH 15 to 30 days, the volatile solids removal is 55 to 60% with a biogas production from 500 to

600 L/kgVS·d; removing PS VS is from 32 to 40% with a biogas production of 250 to 350 L/kgVS·d in mixtures thereof with minor HRT 10 d, VS removal is 40 to 50% with production biogas from 450 to 550 L/kgSV·d. Mesophilic reactors are efficient in removing enterovirus[33], but ineffective in the elimination of viable nematode eggs and only Class B biosolids[34] is achieved. With advantages such as: the control and elimination of odor associated with mud, improving the solubility of N and P fertilizer for their action and high removal VFA. They tend to be more robust and tolerant than the thermophilic. In thermophilic digester the destruction of organic solids is 56%[35], no foaming problems, but have low VFA removal causing destabilization propionate accumulation, and reduced odor removal efficiencies of proteins and lipids[36] and produces class A biosolids[37]. Thermophilic digesters are of 1.5 to 2.5 times more efficient than mesophilic but much more sensitive to high concentrations of ammonium because with increasing temperature the molecular form, which is more toxic than the ionized favors predominating free ammonia according to the balance between molecular shape and ionized ammonia. Although pathogenic bacteria are destroyed more rapidly at temperatures above 53°C (Table 1.9) than 35ºC, some bacterial endospores as Clostridium perfringens, Bacillus cereus and Bacillus anthracis can survive 53ºC transmitted through biosolids[38]. Furthermore, a complete mixing reactor, without recirculation of solids, the HRT matches the SRT. If the SRT solids recirculation is greater than HRT, the retention time affect the rate of gas production. At the other equal conditions, the efficiency of the process (% substrate converted into biogas fed) increases with retention time to an asymptotic value. There is a minimal SRT where the destruction of solids is less than 30% with SRT between 15 and 20 days, biogas production improvement 35ºC. While the hydraulic retention time (HRT), it is important to establish the organic load, time of bacterial growth and the subsequent conversion of soluble organic materials into biogas product of the destruction of the VS[39].

Objectives: Evaluate the anaerobic digestion (AD) in two steps from mixtures of primary and secondary sludge in upflow reactors in series.

METHODS

Two tubular jacketed glass reactors were used; design volume of working volume 10 L and 8.6 L. The biomass used as inoculum were collected from a UASB domestic water treating the delegation Xochimilco with a concentration of 27 g/L of VS. During the startup and stabilization, RAMM mineral medium[40] was used, with glucose as carbon source to achieve acidogenesis conditions in the mesophilic acidogenic reactor (MAr) and sodium acetate to the development of conditions thermophilic methanogenic reactor (TMr). The primary sludge (PS) was collected from the blowdown line primary and secondary sludge clarifier (SS) line activated recirculation plant treating municipal wastewater sludge Cerro de la Estrella in Mexico City. The PS was sieved to remove the trash (cigarette butts, kitchen waste, etc., through a stainless steel sieve of aperture 3.36 mm, diameter 203 mm and overall height of 66.6 mm. With an average concentration of 19.37 TSS g/L (std. std. 9.8) while the average SS present a concentration of 8.7 g/L (std. std. 4.92) TSS. The amount of concentrated sludge (primary and secondary) to prepare the feed mixture in the first reactor (MAr) was performed using the equation $C1V1=C_2V_2$.

Experimental Design: The mesophilic acidogenic reactor 35±3°C was operated without control of pH, agitation or recirculation. PS fed proportions: SS (volume/volume) of: 30:70, 70:30 and 50:50 to evaluate the effect of the volumetric organic load (Bv) and HRT of 1, 2 and 3 days in the destruction suspended solids, and used only a fraction of pre-digested sludge by MAr to feed thermophilic methanogenic reactor (TMr) to 55±1°C 1, 2, 4 and 6 days of HRT (Figure 1).

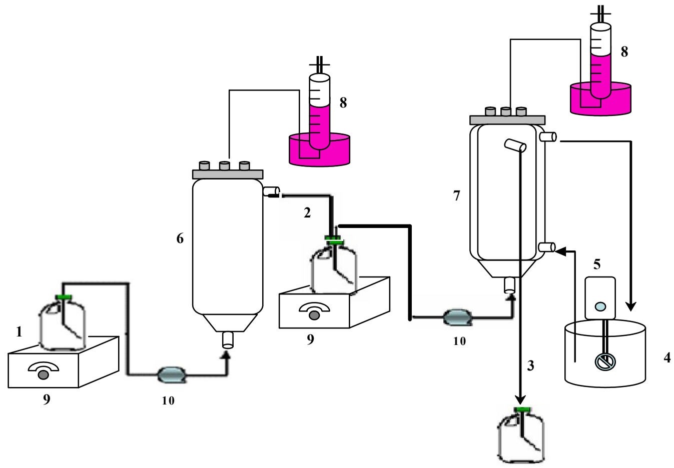

Figure 1: Process description. 1) raw sludge, 2) Mud predigested, 3) stabilized sludge, 4) Termorecirculador 5) Recirculation of water (55±1°C), 6) MAr 35±1°C, 7) TMr to 55±1°C, 8) Column bus biogas with saline, 9) Grill agitation and 10) peristaltic pump.

The operating conditions in different runs in which the experiment was conducted are shown in Tables 2 and 3.

Table 2: Operation conditions of MAr.

Run	I	II	III	IV	V	VI	VII
Period (d)	71-113	124-167	174-184	237-293	316-426	470-525	533-736
Proportion (PS:SS)	30:70	30:70	30:70	70:30	50:50	50:50	50:50
Bv (g COD/L·d)	5.5	3.9	7.5	14.2	7.3	3.6	2.4
Bv (g VSS/L·d)	2.4	2.8	5.3	10.1	4.3	2.15	1.2
HTR (d)	1.0	1.0	1.0	1.0	1.0	2.0	3.0
STR (d)	34.2	32.6	11.3	12.5	11.1	9.2	17.2

Table 3: Operation conditions of TMr.

Run	I	II	III	IV	V	VI	VII
Period (d)	71-113	124-167	174-184	237-293	316-426	470-525	533-736
Bv (g COD/L·d)	3.3	3.2	4.9	9.3	2.2	0.8	0.3
Bv (g VSS/L·d)	1.7	2.0	3.5	7.2	1.5	0.4	0.2
HTR (d)	1.0	1.0	1.0	1.0	2.0	4.0	6.0
STR (d)	19.6	22.9	7.4	15.9	8.01	16.9	14.08

Analytical Techniques: The evaluation of the main parameters of primary sludge (PS), secondary sludge (SS), a mixture of PS: SS fed to acidogenic mesophilic reactor (AMr) (influent), mud AMr predigested by 35 ± 3°C (effluent) and sludge digested by the MTr at 55°C (effluent) for process control (analysis parameter difference) between the sludge and the treated sludge crude mixture without treatment was performed as follows: For the analysis of the soluble fraction, the samples centrifuged at 5,000 rpm in a centrifuge with a diameter of 200 mm for 10 minutes and subsequently filtered through glass microfiber filters of 55 mm diameter and 1.2 .mm porosity.

The analysis of volatile fatty acids (VFA), was determined by gas chromatography (Hewlett Packard model 5890 series II) with a flame ionization detector (FID) and capillary column Superox FA, AT 1000, using an injection volume of 0.2 PL, from a prepared sample (filtrate volume: 950 L and 50 L of HCl at 50%). The team worked under the following operating conditions: column temperature (120 to 140°C) with increase of 10°C/min, injector temperature 130°C, detector temperature 150°C, N_2 as carrier gas at 3 mL/min. The composition of biogas (CH_4 and CO_2) was evaluated by gas chromatography with thermal conductivity detector (Gow-Mac Instruments Co. 550 Series) with 80/100 column Carbosphere, operating conditions were: column temperature, 140°C; detector temperature, 190°C; injector temperature, 170°C; filament current of 120 mA, helium pressure of 40 psi; helium flow of 25 mL/min. The pH was determined with a potentiometer table (Corning pH/ion Analyzer Model 455). The chemical oxygen demand (COD), total suspended solids (TSS) and volatile suspended solids (VSS) were analyzed according to the standard method[41]. Total and soluble carbohydrates by the phenol sulfuric technique[42] and the protein content by Lowry *et al.* [43]

Characterization of primary and secondary sludge: Table 4 shows the averages of the main parameters tested 16 batches of primary sludge (PS) and secondary sludge (SS). Significant scatter in the data is observed due to the variability present sludge along the different seasons.

Table 4: Characterization of primary sludge and secondary (n = 16)

Parameter	Units	PS	SS
pH		6.24± 0.65	6.85 ± 0.44
TS	(g/L)	9.59 ± 4.86	9.6 ± 5.31
VS	(g/L)	5.73 ± 2.81	7.35 ± 4.16
TSS	(g/L)	9.13 ± 4.63	8.7 ± 4.92
VSS	(g/L)	5.48 ± 2.56	6.91 ± 3.93
COD_T	(g/L)	9.34 ± 4.64	8.59 ± 4.77
COD_S	(g/L)	0.53 ± 0.26	0.31 ± 0.18
CHO_T	(g/L)	0.15 ± 0.08	0.054 ± 0.029
CHO_S	(g/L)	0.009 ± 0.005	0.002 ± 0.0009
$Protein_{Tot.}$	(g/L)	6.54 ± 3.35	8.51±4.6
$Protein_{Sol.}$	(g/L)	0.89 ± 0.45	0.015 ± 0.008

Results expressed as mean ± standard deviation.

Table 5 shows the characteristics of the mixture of primary sludge (PS) and secondary sludge (SS) that is fed to the mesophilic acidogenic reactor (MAr).

Table 5: Characterization and MAr feed streams.

Run HRT (d) SRT (d) Bv (g/L·d) PS:SS	I 1 34.2 5.5 30:70	II 1 32.6 3.9 30:70	III 1 11.3 7.5 30:70	IV 1 12.5 14.2 70:30	V 1 11.1 7.3 50:50	VI 2 9.2 3.6 50:50	VII 3 17.2 2.4 50:50
pH	6.5±0.2	6.5±0.5	6.7±0.6	6.8±0.5	6.5±0.2	6.5±0.2	6.5±0.3
TS (g/L)	4.5±0.7	4.6±0.3	8.7±0.3	16.3±0.7	8.5±0.8	8.8±0.8	8.4±0.4
TSS (g/L)	3.7±0.6	4.0±0.5	8.3±1.0	14.6±0.9	7.5±0.9	7.4±0.7	7.6±0.5
VSS (g/L)	2.4±0.5	2.8±0.6	5.3±1.2	10.1±1.3	4.3±0.7	4.3±0.8	3.7±0.3
COD_{total} (g/L)	5.5±0.1	3.9±0.4	7.5±0.1	14.2±0.6	7.3±0.1	7.3±0.1	7.3±0.2
$COD_{soluble}$ (g/L)	ND	0.2±0.01	0.3±0.04	1.0±0.2	0.5±0.01	0.45±0.03	0.5±0.1
VFA (g/L)	0.07±0.01	0.07±0.01	0.1±0.03	0.2±0.1	0.12±0.08	0.12±0.03	0.09±0.065
Acetate (g/L)	0.03 ±0.002	0.03 ± 0.005	0.05 ± 0.005	0.12±0.07	0.07 ± 0.002	0.06± 0.02	0.05±0.045
Propiónate (g/L)	0.02 ± 0.005	0.02 ± 0.003	0.02 ± 0.003	0.03±0.01	0.02 ± 0.001	0.02 ± 0.008	0.02± 0.01
Isobutírate (g/L)	0.01 ± 0.001	0.014 ± 0.004	0.02 ± 0.002	0.02±0.01	0.02 ± 0.001	0.03± 0.004	0.01 ± 0.006
Butírate (g/L)	0.007 ± 0.006	0.007 ± 0.001	0.01 ± 0.02	0.03±0.03	0.01 ± 0.006	0.01 ± 0.001	0.009± 0.004
$Protein_{total}$ (g/L)	3.1±0.2	3.1±0.1	6.1±0.2	12.4±0.5	5.9±0.7	5.9±0.3	4.6±1.2

ND: not determined; VFA: volatile fatty acids. Results expressed as mean ± standard deviation.

RESULTS AND DISCUSSION

Mesophilic acidogenic reactor behavior in the hydrolysis of volatile suspended solids (VSS) and training COD_S: Figure 2 shows the formation of COD_S from destroying the VSS; the diamonds represent the VSS in the influent and the tables VSS in the effluent. COD_S triangles represent influent and circles COD_S in the effluent which was formed from the destruction of the suspended solids. Increased production of COD_S (1.4±0.2 and 1.75±0.2 g/L) and destruction of VSS 33.9 and 28.6% was observed for runs III and IV PS ratios: 30:70 and 70:30 SS and loading 5.3 and 10.1 solids gVSS/L·d respectively a day HRT compared with information in the entry, relative to other runs (I, II, V, VI and VII) with proportion of PS:SS; 30:70 and 50:50, lower solids loading and HRT of 1, 2 and 3 days. These results are similar to those reported by Donoso *et al.*[44] and lower than those reported by Cheunbarn and Pagilla[45] who report a 71.3% reduction in a mesophilic VSS/mesophilic system HRT of 3.1 days in the first phase and 9.1 days for the second phase.

Miron *et al.* [46] achieved a 33% increase in the hydrolysis of organic matter from primary sludge, the STR to vary between 3 and 15 days in completely stirred reactors at 25°C. But lower than those reported in the literature in mixtures of primary and secondary sludge (PS: SS) where efficiencies digested volatile suspended solids reduction of 50 to 60% in mesophilic systems are reached [47,48]. Possible reasons why the reduction of solid was unsatisfactory are: 1) Availability of biodegradable solids in the sludge mixture (biodegradability higher secondary sludge to primary sludge) (87% versus 43%)[48], 2) HRT who had surgery AMr in literature is reported for anaerobic digesters mesophilic HRT greater than 20 days to achieve a reduction in VS of 40%, 3) operating temperature and that the rate of hydrolysis of suspended solids is reported to increase as it increases[3,32,].

With increasing temperature, the hydrolysis and acidification of primary sludge[49,50] is improved. and 4) the pH due to the effect on hydrolysis and acidification of secondary sludge in the following order:

alkali>acid>neutral. Observed at alkaline pH increased the rate of hydrolysis of the solid and consequently the formation of VFA[51]. Zhang *et al.* [52]observed the same result in activated sludge fermentation. Mahmoud *et al.* [32] in their study of the effect of STR and temperature on hydrolysis, acidification and methanogenesis of primary sludge reactor CSTR, they found the greater stabilization to 30 days of STR to 35ºC and 10 to 15 days at 55ºC achieving a 39 to 60% degradation of organic matter. As the rate of hydrolysis of the solids is greater than 55°C, that at 20 and 35°C during fermentation of primary sludge[49].

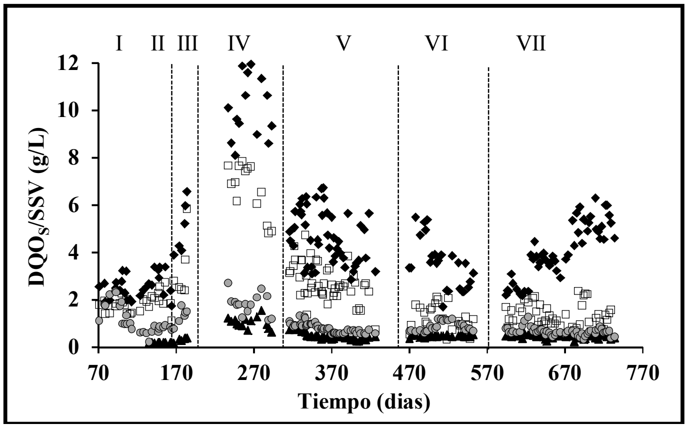

Figure 2: Concentration of VSS and COD_S training in MA reactor.
(◆) VSS in the influent, (□) VSS in the effluent, (▲) COD_S in the influent and (○) in the effluent COD_S

From Figure 2, the figure 3 showing the effect of the variation of the organic filler (Bv) in destroying solids with rate (US) of 1.8 and 2.93 kgVSS/m^3·d (runs III and IV) is constructed and η = 33.9 and 28.6%. It can be concluded that the reaction rate (US) is directly proportional to the fed solids loading.

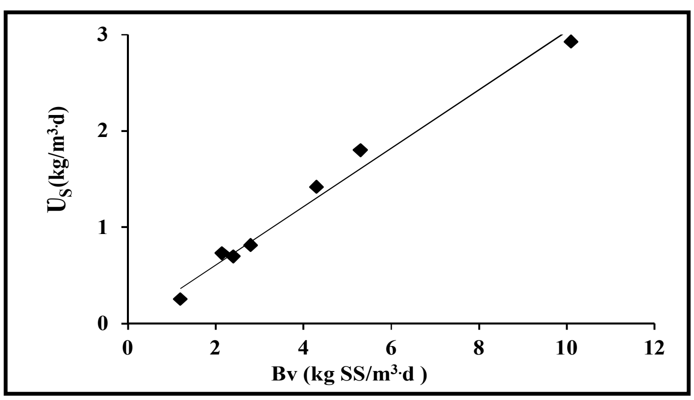

Figure 3: Effect of organic loading (Bv) in the rate of destruction solids with η = 33.9 and 28.6%, r2 = 0.9816.

Figure 4 shows the effect of the SRT in the rate of destruction of solid sludge in mixtures with proportions of PS: SS; 30:70, 70:30 and 50:50 in the MAr. It is observed that the higher solids loading (Corrida IV = 10.1kg_{SSV}/m^3·d), faster destruction short STR (12.5 days) compared to the other runs (lower solids loading), where the SRT were more long (SRT>17 days). Because it is kept not fixed one of the two parameters (SRT or Bv) and varying one of them, one cannot conclude whether the SRT had any effect on the rate of destruction of the solid, but the analysis above facts, the solids loading plays an important role in the destruction of organic solids.

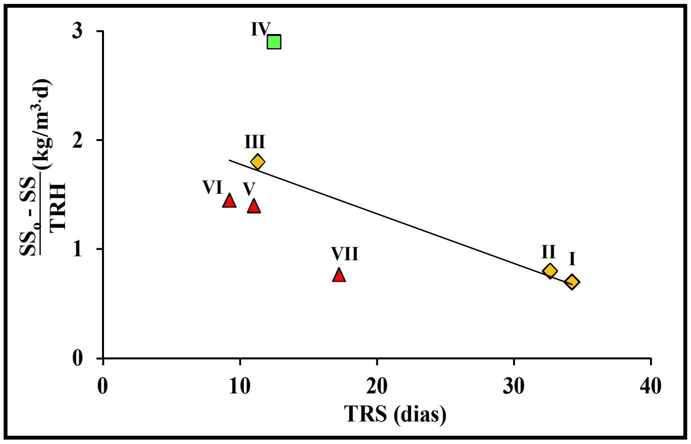

Figure 4: Effect of SRT (d) speed in solids destruction mixtures
LP: LS; 30:70 (◇) runs I-III, 70:30 (□) 50:50 IV run (▲) runs V-VII.

VFA production: Figure 5 shows the VFA production in terms of soluble COD in the effluent AMr. Low production of VFA 0.22, 0.25, 0.23, 0.28 and 0.32 g/L at pH values of 5.4, 5.8, 5.4, 5.7, 5.7 and 5.1 were observed during the runs I to VI in 0.36 respectively with a maximum in VI run a 2-day HRT. But lower concentration (0.2 g/L) during the run seventh pH 7.2 and 3 days HRT at the time that a change is observed in the produced biogas volume and composition (68.3% CH_4) compared to cumshot above (Figures 3.6 and 3.9). The reason why the low VFA production was attributed to that under these conditions no secondary sludge hydrolysis to produce more soluble substrates for acidification and consequently increased. In literature optimum pH for the acid phase bioreactor during operation[53] between 5.0 and 6.0 is mentioned.

Carrozzi and Steinle[36] observed that the concentration varies with HTR VFA finding HRT less than 5 days and pH<6 VFA concentration of 42 mM, with HRT between 10 and 15 days one 9 mM concentration and HRT>15 days, less VFA concentration of 2.5 mM; noting that the pH was less than 6 to TRH less than 5 days and the pH was increased to greater HRT 7.7 to 5 days as a result of the ammonia produced by the hydrolysis of proteins. Elefsiniotis and Oldham[54] observed that the distribution of volatile fatty acids (VFA) is affected by the change in the TRS for the AD of primary sewage sludge.

Miron *et al.* [46] demonstrated that the hydrolysis of lipids and carbohydrates of primary sludge increases with increasing STR and the poor solubilisation of organic matter to hydrolysis therefore suspended solids affects acidogenesis[55]. The use of PS in the mixture with SS is used to favor the formation of soluble products (COD_S) and VFA production by fermentation[30]. Shana and Assadi[56] in CSTR reactors with organic loads 21.4 kg COD/m^{3}·d, HRT of 2-4 days and proportion of PS:SS (70:30) at 35°C, resulted in an increase of 373% VFA relative to the VFA initial sludge in crude composition; acetic acid (38.3%), propionic acid (35.16%), N-butyric acid (11.2%), I-butyric acid (4.78%), I-valeric acid (4.3%) and Nvaleric acid (6.3%). And refer to VFA production is a function of the organic load, the volatile fraction content and pH, and that increasing levels of pH to 5.5 during fermentation of primary sludge acetic acid significantly increased by 70%, while a decrease, the VFA also decreases production of propionic acid and prevalence acids 4 and 5 carbon atoms[57] with. Yinguang *et al.* [51] report that at pH values (pH = 4.0, 5.0) acidogenesis is favored while at alkaline pH (pH 9-11) the hydrolysis is favored.

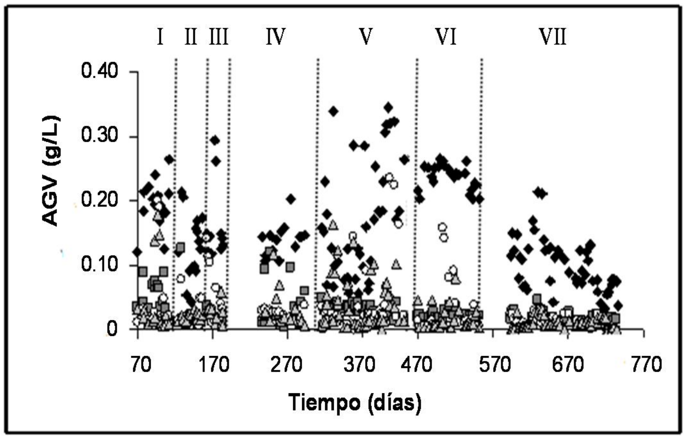

Figure 5: AGV trained mesophilic acidogenic reactor.
Acetate (◆) propionate (■), isobutyrate (△) and butyrate (○).

Biogas production and composition in Mar: Figure 6 shows the biogas production and composition at different solids loadings and HRT (Table 3.2). It is observed during the runs IV (HRT = 1 day) and run VI (HRT = 2 days) decreased production of biogas averaged 12.38 $mL/L_R{\cdot}d$ with an average composition of 66.8% compared CO_2 produced during the run VII to 3 days of TRH (52 $mL/L_R{\cdot}d$) with an average composition of 68% CH_4 yield of 0.4 m^3CH_4/kg_{VSrem}.

It is concluded that the composition of the feed mixture (50% PS and 50% SS) influenced the change in pH as a result, production and biogas composition. Comparatively methane productivity during the AD of PS and SS is higher when stabilized PS[58]. The methane production and composition was similar to that reported by Yinguang *et al.* [51] mention that is affected by the pH and HRT, reaching the maximum production at pH 6 and 8 days HRT.

The table 6 represents the average number of days of operation when the reactor reached the stationary phase in each run is constructed.

In Table 6 and Figure 7 shows the effect of organic loading on the Elimination of COD_T is built; observed that the best efficiency of removal (η = 41%) is attained with a ratio of PS:SS 50:50 with HRT = 1 day and organic load (Bv = 7.3 $kg/m^3{\cdot}d$) with a speed (Ʊ = 3 $kg/m^3{\cdot}d$) relative to other mixtures PS:SS at HRT of 1, 2 and 3 days. Removing greater COD_T a long HRT (run VII) would be expected, as reported in the literature that to solubilize 30-50% of the COD_T or of volatile solids (VS) it takes more than 30 days in STR [59]. But this will not happen because the solids loading is lower.

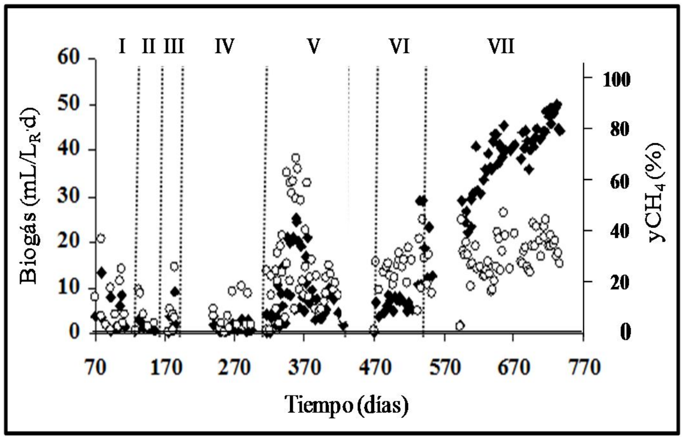

Figure 6: Production (○) and biogas composition (◆) in the acidogenic reactor.

Table 6: Features hydrolyzed sludge and biogas MAr.

Corrida	I	II	III	IV	V	VI	VII
pH	5.4±0.4	5.8±0.5	5.4±0.3	5.7±0.3	5.7±0.2	5.1±0.2	7.2±0.4
TS (g/L)	3.0±0.4	3.3±0.3	6.0±2.3	10.9±1.8	5.5±1.3	3.6±1.2	3.1±0.8
TSS (g/L)	2.5±0.4	2.9±0.4	5.5±2.0	9.4±1.7	4.4±1.2	2.1±0.8	1.8±0.5
VSS (g/L)	1.7±0.3	2.0±0.5	3.5±1.4	7.2±0.6	2.9±0.7	1.4±0.6	1.4±0.4
COD_T (g/L)	3.3±0.4	3.2±0.3	4.9±0.2	9.3±1.01	4.3±1.0	3.1±0.5	2±0.9
COD_S (g/L·d)	ND	0.7±0.2	1.4±0.2	1.75±0.2	0.8±0.07	0.45±0.03	0.2±0.02
VFA (g/L)	0.36±0.2	0.22±0.09	0.25±0.08	0.23±0.1	0.28±0.13	0.32±0.07	0.2±0.1
Acetate (g/L)	0.2 ±0.04	0.14± 0.05	0.19 ± 0.07	0.14±0.03	0.16 ± 0.1	0.25 ± 0.03	0.16±0.08
Propionate (g/L)	0.05 ± 0.03	0.02 ± 0.03	0.01 ± 0.003	0.04±0.03	0.03 ± 0.01	0.02 ± 0.008	0.02±0.009
Isobutirate (g/L)	0.07 ± 0.11	0.04 ± 0.04	0.03 ± 0.02	0.02±0.01	0.05 ± 0.07	0.04 ± 0.05	0.01±0.008
Butirate (g/L)	0.04 ± 0.06	0.02 ± 0.007	0.02 ± 0.02	0.03±0.03	0.04 ± 0.04	0.02 ± 0.02	0.01±0.008
$Protein_{Total}$ (g/L)	2.3±0.2	2.2±0.2	3.9±0.22	8.2±0.75	4.03±0.49	2.4±0.32	0.9±0.39
$Protein_{Soluble}$ (g/L)	0.19±0.06	0.22±0.05	0.5±0.03	0.78±0.4	0.36±0.1	0.4±0.02	0.32±0.1
$Q_{BiogásTPS}$ (mL/L_R·d)	11.2±9.8	6.3±4.8	7.7±8.4	5.5±4.3	24.0±17.1	19.6±5.8	52.6±14.3
CH_4 in the biogás (%)	38.4	25.4	38.9	27.1	38.3	31.1	68.3

TPS: standard temperature and pressure; COD: Chemical oxygen demand. Results expressed as mean ± standard deviation.

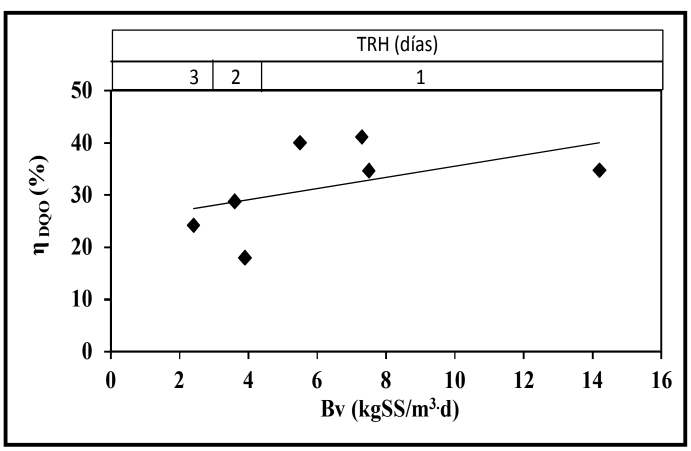

Figure 7: Effect of organic load (Bv) in removing COD_T (◆).

Evolution of pH: Figure 8 shows the evolution of pH. Average pH is observed in the effluent of 5.5 with a rising trend in the last run (pH = 7.2), because part of the fermented material was converted to methane.

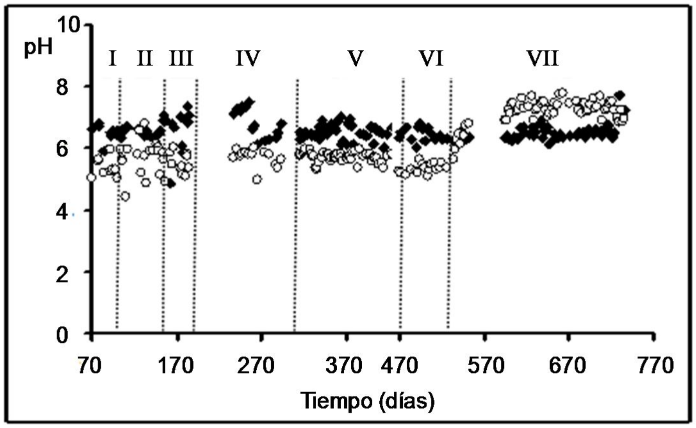

Figure 8: Evolution of pH in the acidogenic reactor; Influent (◆) and effluent (○).

For the analysis of reactors, of the total VFA (ionized and protonated) constant methane production (k_3) is estimated taking into account only the VFA ionized (B^-) depending on the pH of each run.

$$B^- = f\,(pH, A_t) \tag{6}$$

$$pH = pka + \log \frac{B^-}{BH} \tag{7}$$

From the Henderson Hasselbalch and that

$$B_t = B^- + HB \tag{8}$$

$$B^- = B_t/(Fi + 1), \tag{9}$$

Where:

$$Fi = 10^{(pKa\ -\ pH)} \tag{10}$$

Estimating reaction rate constants (k): Table 7 shows estimates of the reaction rate constant values that are held in the AMr according to the kinetic model of anaerobic digestion (AD).

Table 7: Reaction rate constants (k) in the rAM.

Reaction	Reaction rate K	K (1/d)
SS → DS →VFA→ CH_4	$r_{SS} = k_1SS$	$k_1 = 0.0681$
	$r_{SD} = k_1SS - k_2SD$	$k_2 = 1.12$
	$r_{AGV} = k_2SD - k_3AGV(B^-)$	$k_{AGV} = 0.058$
	$r_{CH4} = k_3AGV\ (B^-)$	$K_3 = 0.35$

The value of k (d^{-1}) in the reaction rate (RSS = k_1SS) compared to the value of the kinetic costant k (d^{-1}) VSS reduction and stabilization of the mixture of biomass PS:SS, was higher than reported by Arnaiz *et* *al.* [48] who report VSS reduction values of 0.035, 0.044 and 0.022 d^{-1} to PS, SS and mix respectively. But less than the values of the kinetic constants k_1, k_2 and k_3 reported by Siegrist *et al*,[60] to mix PS:SS (0.25, 5.0 and 0.5 d^{-1}) respectively.

Methanogenic thermophilic reactor behavior in the destruction of volatile suspended solids (VSS) and training COD_S: The figure 9 shows the effluent COD_S MTr from destruction of volatile suspended solids (VSS); the diamonds represent the VSS in the influent and the tables VSS in the effluent. COD_S triangles represent the influent and circles the COD_S in the effluent. It is noted that once the reactor is pre-digested sludge acclimated to the first reactor as a substrate, the maximum destruction of VSS and COD_S conversion is reached during the run III (66 and 70%) to an organic content (CO) of 3.5 kgVSS/m^3·d decreasing as a result of the composition of the mixture fed into the first reactor during the run MAr IV by 55 and 62% at a load of 7.2 kgVSS/m^3·d.

From the three subsequent (lower solids loading) fits HTR will discarding the effluent from the first reactor. The guiding criterion for adjusting the HRT in the last bull was seeking maximum elimination of pathogens and parasites. Best VSS destruction and conversion of COD_S to 2 days of HRT was observed during the run V (69 and 90%) to low CO = 1.5 kgVSS/m^3·d regarding bull VI and VII. In thermophilic systems removal efficiencies of volatile solids are 40 to 50% [61] but can be up to 50 to 70% [48]. De la Rubia *et al.* [62,63] showed no difference in the efficiency of destruction of VS between mesophilic and thermophilic reactor (53% in both reactors). In systems of two-stage thermophilic-mesophilic stripping for VS is between 38 and 45% for retention times of less than 15 days and 58.8% for SRT greater than 21 d.

Rubio *et al.* [64] in a thermophilic-acidogenic system (TAS) fed with a mixture of primary-secondary sludge at 56 and 44% in volume and solids loading 10 kgVSS/m^3·d at 3 days of the effluent from this reactor fed in parallel a mesophilic methanogenic reactor (MMr) and a thermophilic methanogenic (TMr) to 13 days HRT VSS get a reduction in the TM-MM system of 31% and 28% in the AT-MT arrangement and 10 days HRT 32% in both systems. In systems with two thermophilic-mesophilic stages VS removals occur between 38 and 45%, for retention times shorter than 15 days and 58.8% to greater than 21 d SRT during the thermophilic AD with short SRT (between 5 and 10 days) 32% VS destruction and 37% more methane production compared to conventional mesophilic AD systems[63] is achieved.

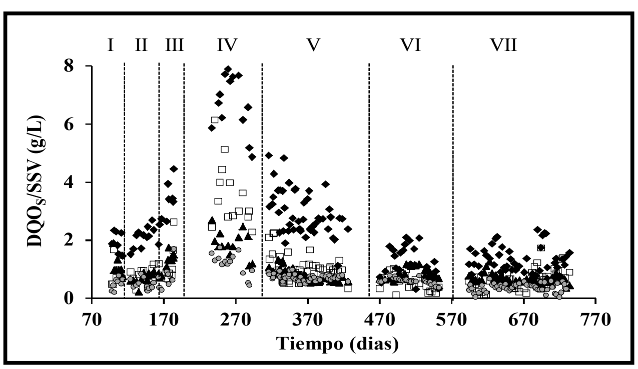

Figure 9: SSV and CODS concentration in the reactor effluent RMT.
(◆) VSS in the influent, (□) VSS in the effluent, (▲) SCOD in the influent and (●) in the effluent CODS

From Figure 10 shows the effect of the organic load in solids destruction rate is constructed and that the higher the concentration of solids in the effluent from the AMr (predigested slurry) faster destruction observed MTr solids in the reactor.

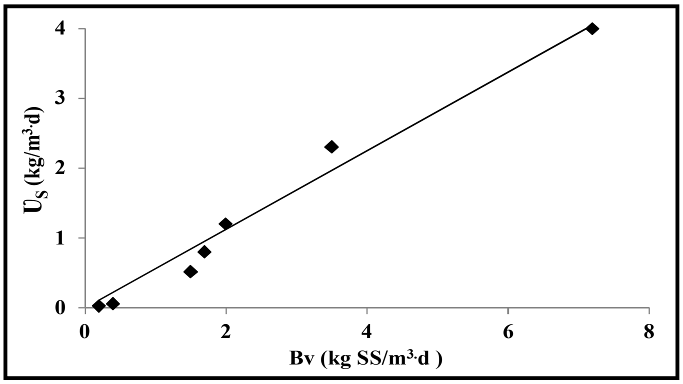

Figure 10: Effect organic load (Bv) in the rate of destruction solids (Us) with an efficiency (η) of 56.3% and r^2 of 0.9767.

Removal COD_T : Figure 11 shows the behavior of the reactor MTr on removing the sludge remaining in COD_T predigested by MAr. It is observed that most COD removal occurs in run IV (51%) with a load of 7.2 kgVSS / m^3·d, a STR of 15.9 days and 1 day HRT. This result can be compared with that reported by De la Rubia *et al.* [62] who mention a removal efficiency COD_T in the thermophilic reactor of 35.3% compared to the value achieved in the mesophilic reactor (52.8%) in reactors CSTR reactors mixtures PS:SS 27 SRT days and organic loading of 1.3 kgVSS/m^3·d. Buffiere *et al.* [65] in their study reported a LP COD_Tremoving 25% to 55°C at a HRT of 10 days.

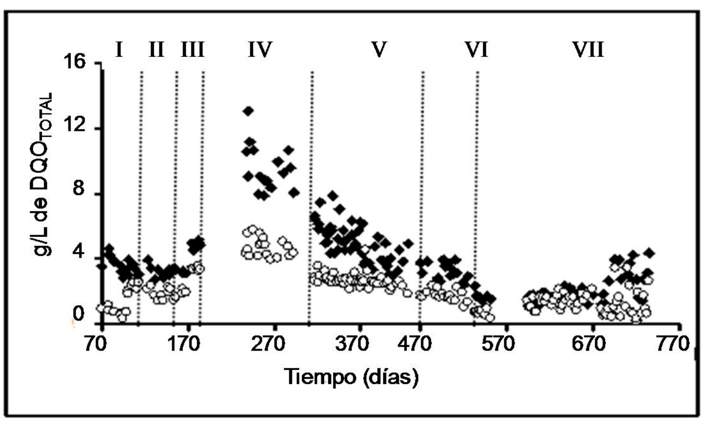

Figure 11: COD_T concentration in the reactor TMr; Influent (◆) and effluent (○).

Figure 12 shows a high correlation between the organic content and COD removal which provides the pre-digested sludge solids is constructed by AMr. It is found that a lower organic content (<3 kgVSS/m^3·d) at 2, 4 and 6 days of HRT, the destruction of solids and COD removal is only 19.7 and 12.3%. With organic loads 3 to 5 kgVSS/m^3·d, the results improve by 57.7 and 35%, but with higher organic loads to 8 kgSS/m^3·d and HRT=1 day, the destruction of solids but does not improve the removal of COD_T (51%) following the solids concentration is reached in the slurry bed reactor at different heights based on the organic load supplied and the capacity of the active biomass (hydrolysis) for disposal.

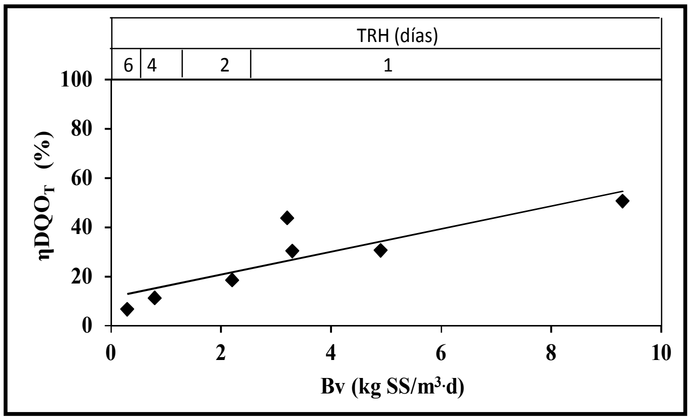

Figure 12: Effect of organic load (Bv) in removing the COD_T (◆) with η = 46.3% and r^2 of 0.743.

VFA unconverted to methane (CH_4) : Figure 13 shows the VFA remaining in the effluent from the MTr (0.12, 0.1, 0.14, 0.17, 0.13, 0.081 and 0.04g/L) from those who enter; 0.36, 0.22, 0.25,0.23, 0.28, 0.32 and 0.2 g/L. Lower VFA concentrations observed during all runs to 0.17 g / L acetate and predominate lesser other VFA concentration that accounts MT reactor behavior in conversion to methane. It is appreciated that to the extent that it will switch to the HRT (at 2, 4 and 6 days) the affected VFA but also the production of biogas.

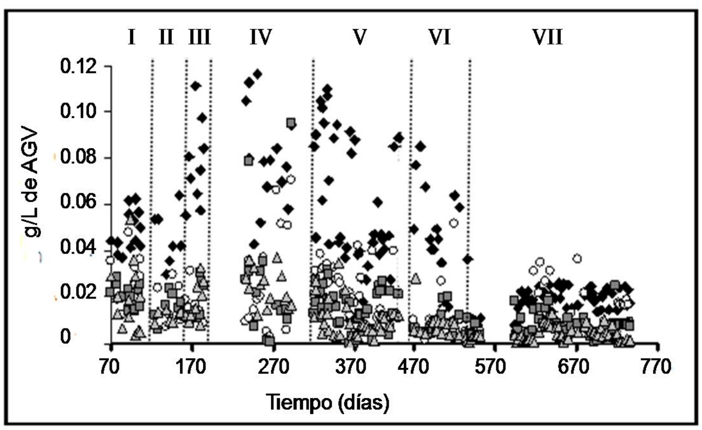

Figure 13: AGV remaining in the reactor stabilized by methanogenic sludge.

Acetate (◆), propionate (○), isobutyrate (■) and butyrate (△).

Yue[66] reported in thermophilic effluents of a phase, values VFA 800 to 2.200 mg/L at 25 days HRT, which is 83% more than that obtained in mesophilic systems HRT of 10-40 days. Han & Dague[67] in a thermophilic-mesophilic system achieved concentrations between 1,600 and 2,200 mg/L with HRT of 3.3 to 5 days and 180 to 300 mg/L of VFA with HRT of 6.7 to 10 days. Cheunbarn and Pagilla[45] in a study of reactors; thermophilic-mesophilic reported VFA concentrations of 3500 mg/L at concentrations of 260 to 450 mg/L of acetic acid in the mesophilic reactor effluent relative to the VFA concentration in the influent (960 mg/L). Tsakou *et al.* [68], reported a 53.3% formation of VFA at SRT of 10 days. Eckenfelder and Wesley[69] reported that the VFA concentration remains between 20 and 200 mg/l according to the supplied organic load.

Biogas production: Figure 14 shows low biogas production (average of 42.08 $mL/L_{R \cdot d)}$ during the first four runs a day HRT. It is observed that as the HRT increases to 2, 4 and 6 days enhances biogas production in 64.8, 108.5 and 131.8 $mL/L_{R \cdot d}$ with an average content of 74% methane organic loadings of 1.45, 0.35 and 0.23 $kg_{VSS}/m^{3 \cdot}d$, production speeds of 0005 and 0.09 $m^3CH_4/m^{3 \cdot}d$ and yield 0.4 $m^3CH_4/kgVS_{rem}$.

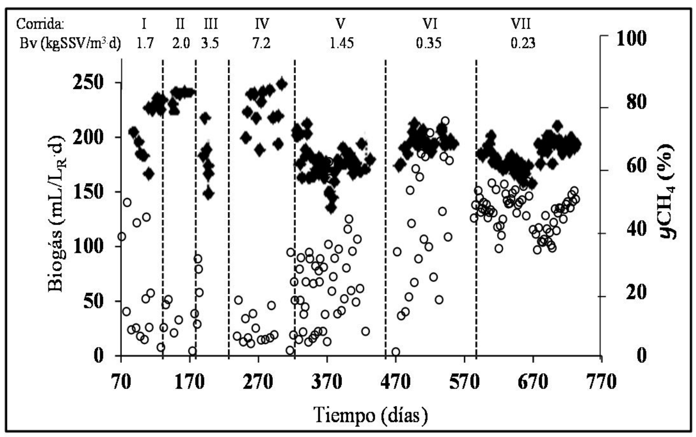

Figure 14: Production (○) and composition (◆) of biogas in the methanogenic reactor.

This result was similar to that reported by Rubio *et al.* [64] study in MM but less than that obtained in the MT reactor similar to that reported for reactor Vigueras *et al.* [70]. Yue *et al.* [66] in CSTR reactors at 55 and 35ºC with 4 and 10 days of STR and organic load of 2.1-2.3 $kgVSS/m^{3 \cdot}d$ reported production of 0.728 $kgCH_4/m^{3 \cdot}d$. So in these systems the specific production of methane is about 0.39 $m^3CH_4/kgVS$ removed[61]. Song *et al.*[71] reported methane production rates from 0178-0230 $kgCH_4/m^{3 \cdot}d$ for organic loadings between 1.21 and 1.44 kg $VSS/m^{3 \cdot}d$. Carrozzi and Steinle[36] and Killilea *et al.* [47] reported values of methane production between 0.392 and 0.525$kgCH_4/m^3 \cdot d$ for organic loads between 1.75 and 2 kg $VSS/m^{3 \cdot}d$. The yield of methane production under thermophilic conditions decreased by 50% compared to that produced under mesophilic conditions[62]. But in a later study De la Rubia *et al.* [63] show that in thermophilic conditions the removal efficiency is independent of SRT when it is greater than 15 d. The same study shows that by decreasing the STR increased the yield of methane is generated. Rubio *et al.* [64] in their study to 13 days HRT reported a biogas production of 1573 mL/d in the mesophilic methanogenic reactor (MM) with yields of 0.4 $m^3CH_4/kgVSS_{rem}$ in thermophilic methanogenic digester (MT) output of 1,054 mL/d with yields of 0.29 $m^3CH_4/kgVSS_{rem}$. Vigueras *et al.*[70] reported yields 0.4$m^3CH_4/kgVSS_{rem}$

($0.12 kgCH_4/m^3 \cdot d$) for the thermophilic reactor. Table 8 shows the results of the treated sludge parameters evaluated by the MTr previously predigested by AMr is Built.

Table 8: Characteristics of the sludge and biogas output TMr.

Run	I	II	III	IV	V	VI	VII
pH	7.5±0.3	7.2±0.3	6.9±0.4	6.9±0.2	7.0±0.3	7.1±0.2	7.2±0.3
TS (g/L)	2.1±0.6	1.9±0.7	3.2±1.3	7.85±1.7	3.0±0.6	2.7±1.1	1.8±0.9
TSS (g/L)	1.6±0.4	1.6±0.7	2.6±0.7	5.85±1.1	1.4±0.8	1.6±0.8	0.6±0.2
VSS (g/L)	0.9±0.4	0.8±0.3	1.2±0.7	3.21±0.7	0.9±0.3	0.6±0.3	0.5±0.2
gVSS/gTSS	0.54	0.49	0.45		0.61	0.38	0.73
COD_T (g/L)	2.3±0.3	1.8±0.3	3.4±0.1	4.6±0.5	2.7±0.3	1.7±0.3	1.2±0.7
COD_S (g/L)	0.54±0.19	0.49±0.18	0.7±0.18	1.36±0.18	0.74±0.14	0.59±0.02	0.44±0.08
VFA (g/L)	0.12±0.02	0.1±0.02	0.14±0.02	0.17±0.1	0.13±0.05	0.081±0.04	0.04±0.01
Acetate (g/L)	0.05 ± 0.01	0.05 ± 0.02	0.09 ± 0.02	0.08 ± 0.02	0.07 ± 0.03	0.045± 0.02	0.02±0.01
Propionate (g/L)	0.03 ± 0.01	0.02 ± 0.01	0.01±0.003	0.03 ± 0.02	0.03 ± 0.007	0.02 ± 0.01	0.01±0.009
Isobutirate (g/L)	0.02 ± 0.005	0.02 ± 0.005	0.02 ± 0.01	0.03 ± 0.03	0.02 ± 0.01	0.01±0.007	0.007±0.005
Butirate (g/L)	0.02±0.02	0.01 ± 0.002	0.02±0.01	0.03±0.03	0.01±0.01	0.006±0.005	0.004±0.003
$Protein_{Total}$ (g/L)	1.9±0.18	1.5±0.19	2.9±0.13	4.03±0.76	2.3±0.49	1.65±0.8	0.36±0.16
$Protein_{Soluble}$ (g/L)	0.23±0.1	0.32±0.02	0.59±0.03	0.93±0.06	0.53±0.15	0.41±0.09	0.41±0.07
$Q_{BiogásTPS}$ ($mL/L_R \cdot d$)	63.1±47.7	30.9±16.4	49.8±31.9	24.5±13.4	64.8±38.6	108.5±60.6	131.8±36.0
CH_4 in the biogás (%)	82.3	90.3	71.8	85.7	71.0	77.2	74.4
L CH_4/g $VSS_{removido}$	64.9	23.3	15.2	5.3	22.9	104.6	108.9

TPS: standard temperature and pressure; COD: Chemical oxygen demand; CH_4: methane; CO_2: carbon dioxide. Results expressed as mean ± standard deviation.

Estimating reaction rate constants (k): Table 9 summarizes the value of the kinetic constants that were estimated at the TMr reactor according to the DA model.

Table 9: Reaction rate constants (k) in the TMr.

Reaction	Reaction rate K	K (1/d)
SS → DS →VFA→ CH_4	$r_{SS} = k_1SS$	$k_1 = 0.0614$
	$r_{DS} = k_1SS - k_2DS$	$k_2 = 4.2$
	$r_{VFA} = k_2DS - k_3VFA\ (B^-)$	$K_{VFA} = 0.0463$
	$r_{CH4} = k_3VFA\ (B^-)$	$K_3 = 0.12$

CONCLUSIONS

- ✓ With the upward flow of suspended solids in the sludge mixture were compacted, hydrolyzed, fermented in VFA and metanizados.
- ✓ The results show that there is no influence of the sludge (PS:SS) in the destruction of solid, but the organic load and the SRT. And it is found that a higher concentration of solids, the faster the rate of reaction (US).

- ✓ We conclude that K_1 acidogenic mesophilic reactor (MAr) is slightly higher than the methanogenic thermophilic reactor (MTr) and k_2 for both reactors is much greater than the value of their K_1 confirming hydrolysis as limiting step of AD.
- ✓ With the value of k_3 (much less than k_2) in the two reactors, slow anaerobic digestion of sewage sludge due to poorly fermentable soluble material in VFA by the MAr and slowness in converting CH_4 VFA confirmed in the MTr.
- ✓ The kinetic constants describe the dynamic behavior of the system, the relationship between the main variables of state, as well as the influence of temperature, mixing, hydraulic retention time, solids concentration and the presence of inhibitors in the process hydrolysis.

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