



Anaerobic codigestion of urban solid waste fresh leachate and domestic wastewaters: Biogas production potential and kinetic

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ABSTRACT

The Biochemical Methane Potential (BMP) of fresh leachate and domestic wastewaters codigestion was determined by laboratory Batch Tests at 35°C over a period of 90 d using a wide range of leachates volumetric ratios from 0% to 100%. To simulate wastewaters plant treatment step, all the ratios were first air stripped for 48 h before anaerobic incubation. The kinetic of biogas production was assessed using modified Gompertz model and exponential equation. The results obtained showed that cumulative biogas production was insignificant in the case of wastewaters monodigestion while the codigestion significantly improves the BMP. Air stripping pretreatment had positive effect on both ammonium concentration and volatiles fatty acids with reduction up to 75% and 42%, respectively. According to the Modified Gompertz model, the optimal anaerobic co-digestion conditions both in terms of maximal biogas potential, start-up period and maximum daily biogas production rate, could be achieved within large leachate volumetric ratios from 25% to 75% with a maximum BMP value of 438.42 mL/g volatile solid at 50% leachate ratio. The positive effect of codigestion was attributed to a dilution effect of chemical oxygen demand and volatile fatty acid concentrations to optimal range that was between 11.7 to 32.3 gO₂/L and 2.1 to 7.4 g/L, respectively. These results suggested that the treatment of fresh leachate by their dilution and co digestion at wastewaters treatment plants could be a promising alternative for both energetic and treatment purposes.

Keywords: Anaerobic codigestion, Biogas, Domestic wastewaters, Fresh leachate, Kinetic models

1. Introduction

Anerobic codigestion of leachate has recently gained interest using different substrates, effluents and technologies [1-3]. Leachates, particularly the young ones, are more and more considered as a source of energy and the most emerging reflexion in that field is associated to food waste and landfill leachates and wastewater codigestion in order to improve anaerobic wastewater plant efficiency and energy dependence [4-6].

For concentrated leachate such as those of the African and southern Mediterranean countries, anaerobic recovery by codigestion could be a promising environmental strategy. Thus, mainly when considering the highly organic constituents content and biodegradable character of these leachates as revealed by many works [7-10]. For Most african countries, the wastewater treatment is still based on activated sludge technology [11] but

the recent development of anaerobic-based wastewaters plants in some countries particularly Morocco and Ghana makes codigestion of young landfill leachate and agro industrial effluents at wastewater plants very attractive.

Codigestion of multiple substrates and wastes has been largely demonstrated to have synergetic effect and increase considerably methane production during anaerobic digestion compared to monodigestion [12]. Previous pilot and full-scale studies focusing on the biogas yield of different organic substrates (agricultural, municipal and food industrial wastes) in mono-digestion and codigestion in batch mode showed that codigesting improved both methane production and process efficiency compared to the single substrate [1, 13-20]. Few data are available regarding the codigestion of landfill leachates and wastewaters. [21] showed that codigestion of leachate with wastewaters sewage sludge increased the biogas and methane yield by 13% and



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16%, respectively compared to the sewage sludge alone. Recently an energetic yield increase up to 80% was achieved with food waste leachate as co-substrate [22]. Similar recent works in which different kinds of food wastes leachates were codigested with wastewaters using different ratios confirmed the hypothesis that co-anaerobic digestion is more likely to realize bio-gasification than single wastewater anaerobic digestion [6]. The mixing ratios of food waste leachate that produces the highest methane yield varied in a large range depending on both wastewaters and leachate characteristics and origin [23]. Simultaneously, it was reported that addition of leachate to wastewater could affect rather negatively wastewater and sludge anaerobic plant [24]. According to fundamental basis of methanogenesis, the most suspected methanogenesis inhibitors associated to codigestion in this case are ammonia and volatile fatty acids since these elements are particularly abundant in young leachates [25-27]. The activated sludge step of wastewater treatment had shown to significantly reduce ammonia although as reported by [28, 29].

This work deals with the emerging perspective of leachate treatment at wastewaters plant and focuses on the combined anaerobic Batch digestion of fresh leachate and domestic wastewaters in order to evaluate the effects of fresh leachate addition as a co-substrate on the overall biogas production stability and efficiency of the anaerobic codigestion process. For this aim, cumulative biogas production for all Batch tests was simulated using exponential rise to maximum and modified Gompertz models as described by [30-33]. The aerobic pretreatment of wastewater at activated sludge step was simulated through air stripping and its effect on ammonia and volatile fatty acids evaluated.

2. Materials and Methods

2.1. Landfill Leachate and Domestic Wastewater Sampling

The leachate used was directly collected from the wastes compactor vehicles before waste dumping at the sanitary landfill of Béni Mellal city, Morocco. The landfill site covers approximately

Table 1. Leachates Characteristics

Parameters	Average value	Standard deviation
pH	5.58	0.33
Conductivity (mS/cm)	24.83	1.64
COD (g/L)	42.6	0.5
TKN (mg/L)	2960	85
VFA (gacetic acid/L)	14.6	0.75
Ammonium (mg/L)	765	25
Total Phosphorus (mg/L)	162	9.5
Sulphates (mg/L)	820	22.6
Chloride (mg/L)	930	84.6
Cadmium (mg/L)	0.019	0.004
Lead (mg/L)	0.33	0.14
Copper (mg/L)	1.56	0.01
Zinc (mg/L)	6.5	1.45
Iron (mg/L)	45.16	1.5

200,000 m² and receives about 160 tons of municipal solid wastes per day with an amount of daily fresh leachates production estimated to 20-60 m³, depending on the season. The full characteristics of this leachate are reported on Table 1. It showed typical composition of the young leachate used with relatively high level of chemical oxygen demand (COD) (42.5 g/L), total Kjeldahl nitrogen (TKN) (2,960 mg/L), ammonia (765 mg/L), volatile fatty acid (VFA) (14.6 g/L) and salts content (24.3 ms/cm). Wastewater used was collected at the municipal wastewater plant treatment; its chemical oxygen demand is low and typical of domestic wastewaters.

2.2. Codigestion Ratios Preparation and Batch Experiments

Five volumetric ratios of leachate/wastewaters (L/W) were prepared for batch anaerobic determination of biochemical methane potential: 100%L (R100), 75%L/25%W (R75), 50%L/50%W (R50), 25%L/75%W (R25) and 100%W (R00). The characteristics of each mixture are summarized in (Table 2).

The batch tests were conducted using standard reactor with working volume of 1.3 liter for a total volume of 1.5 liter. Each ratio was inoculated by 100 mL of granular anaerobic sludge collected from the municipal wastewater anaerobic reactor and then adjusted to pH 7.5 using KOH 0.1N. In order to simulate wastewaters treatment plant step, all the ratios were first air stripped for 48 h before anaerobic incubation. The anaerobic condition was assured through N₂ bubbling and then the reactors were sealed and kept at 35 ± 2°C using heated lab aquarium. The reactors were retired for 5 min manual agitation once a day and the biogas produced was measured every 3 to 4 d by the water displacement method. The incubation was carried out for a period of 90 d until no biogas was detected.

2.3. Kinetic Modeling

The cumulative biogas production kinetics obtained from anaerobic digestion of all batch reactors was assessed by fitting the experimental cumulative biogas data to the exponential rise to maximum and modified Gompertz kinetic model as described in literature [31, 33]. The corresponding equations used are as follows:

Exponential rise to maximum:

$$C = A(1 - \exp(-kt)) \quad (1)$$

Modified Gompertz equation:

$$P = A \exp \left\{ - \exp \left[\left(\mu \frac{e}{A} \right) (\lambda - t) + 1 \right] \right\} \quad (2)$$

Where:

C: cumulative biogas production (mL/gVS)

K: kinetic rate constant (d⁻¹)

P: specific cumulative biogas production (mL/g VS)

A: biogas production potential (mL/g VS)

μ_m : maximum biogas production rate (mL/g VS/d)

λ : minimum time required to produce biogas (d)

t: hydraulic retention time (d)

Table 2. Characteristics of Used Leachates/Wastewater Ratios

	R100	R75	R50	R25	R00
Dry matter (g/L)	39.03 ± 1.4	29.56 ± 1.45	20.09 ± 1.32	10.62 ± 1.16	1.15 ± 0.22
VS (g/L)	26.6 ± 0.12	20.16 ± 0.15	13.71 ± 0.1	7.26 ± 0.08	0.81 ± 0.06
pH	5.58 ± 0.33	5.36 ± 0.35	5.50 ± 0.25	6.56 ± 0.21	7.55 ± 0.11
Conductivity (mS/cm)	24.83 ± 1.64	22.90 ± 1.4	16.70 ± 1.2	9.95 ± 1.24	0.1713 ± 26
COD (g/L)	42.6 ± 0.5	32.3 ± 0.82	22 ± 0.74	11.7 ± 0.55	1.4 ± 0.48
NH ₄ ⁺ -N (mg/L)	765 ± 25	599.68 ± 16	434.37 ± 15	169.0 ± 8	3.73 ± 1.4
VFA (g/L)	14.6 ± 0.75	10.75 ± 0.9	7.21 ± 0.5	3.66 ± 0.4	0.12 ± 0.085

Table 3. Ammonium and VFA Removal Rate by Air Stripping Pretreatment

	NH ₄ ⁺ (mg/L)			VFA (g/L)		
	Initial	Final	Removal (%)	Initial	Final	Removal (%)
R100	765.0	265	65.35	14.60	9.40	35.62
R75	599.68	200.0	66.61	10.75	7.40	31.16
R50	434.37	186.0	62.00	7.21	5.60	22.33
R25	169.00	41.00	75.0	3.66	2.10	42.62
R00	3.73	3.7	0.01	0.12	0.11	8.33

The nonlinear regression and analysis of experimental data was performed on the basis of least squares algorithm using MATLAB2015. The obtained coefficient of determination (R^2) was used to evaluate the performance of the two models. For each set of data, R^2 was obtained by calculating the following ratio (3)

$$R = \frac{\sum_{i=1}^n (xi - \bar{u})(yi - \bar{y})}{\sqrt{\sum_{i=1}^n (xi - \bar{u})^2} \sqrt{\sum_{i=1}^n (yi - \bar{y})^2}} \quad (3)$$

Where, xi and yi are the observed data and \bar{u} and \bar{y} are the calculated averages. The calculation of the correlation coefficient thus makes it possible to obtain an estimate of correlation degree between the experimental variables.

2.4. Analytical Methods

COD in the influent and effluent samples after each treatment was determined by the standard closed reflux colorimetric method [34]. The pH was monitored using a pH meter (HANNA HI2300), ammonia nitrogen concentration was measured using the Kjeldhal method and volatile solid (VS) were carried out following the procedures outlined in standard methods [34]. VFAs concentration was determined using the Volatile Acid Alkalinity Method described in Operations Manual Anaerobic Sludge Digestion [35].

3. Results and Discussion

3.1. The Effect of Air Stripping Pretreatment

The effluent ammonium and VFA concentrations before and

after air stripping pretreatment are reported in (Table 3). Ammonium removal varied from 62 to 75% reducing the initial concentration to 265, 200, 186, 41 and 3.7 mg/L, respectively for R100, R75, R50, R25 and R00. Similar result were reported by others authors for which air stripping was operated at alkaline pH causing highly significant loss of ammonium by ammonia volatilization [36-39]. In our conditions the reduction of ammonium concentration during air stripping could be attributed much more to nitrification as the working pH was less favorable to ammonia loss by volatilization. Air stripping had also positive effect on VFA content with percent reduction that varied from 8% to 42% and this was attributed to VFA volatilization and biodegradation. Final values were 9.4 g/L, 7.4 g/L, 5.6 g/L, 2.1 g/L and 0.11 g/L, respectively for R100, R75, R50, R25 and R00. We expected an increase of VFA as the 48 h of air stripping is quite sufficient to stimulate microbial activity and leachate decomposition and hydrolysis, but it seems that volatilization of short-chain organic and odorous acids was predominant during this step.

3.2. Effect of Codigestion on Cumulative Biogas Production and Kinetic

Biogas production over the 90 d test is illustrated in Fig. 1. No significant biogas was detected for reactor R00 working with only wastewater and this was attributed to its low COD concentration either before or after air stripping. The lowest biogas yield was also recorded in case of leachate monodigestion (R100). For other ratios, biogas values and kinetic showed that codigestion had a positive effect and that leachate dilution by wastewater reduce the start-up period and improves biogas yield. Comparison between reactors showed that the highest biogas yield was achieved at R50 followed by R25. Similar results were obtained

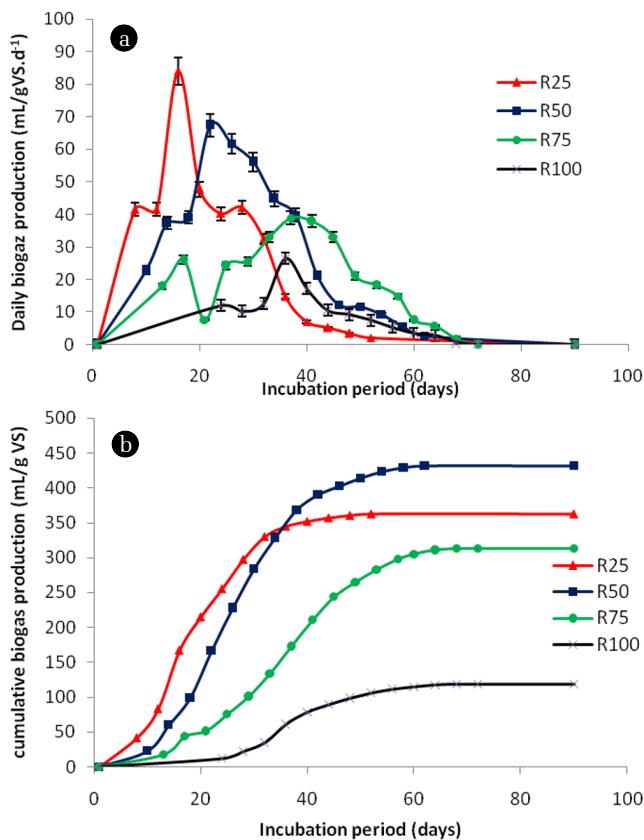


Fig. 1. Biogas production rates (a) and cumulative biogas production (b).

by others authors [40-42] regarding the positive effect of wastewater dilution. By diluting leachate by synthetic wastewater, optimal anaerobic digestion was also achieved at volumetric leachate ratio under 30% with maximum COD removal at 25% ratio [43].

Many parameters could be responsible for yield decrease at higher concentrations of leachates. Taking account the used leachate composition (Table 1) and as ammonium was at values favorable for methanogenesis as documented by literature [44], the observed effects could be attributed to the overall initial composition of leachate and particularly the initial leachate COD and VFAs content that seems to be the most limiting factors in this case. Thus, even though high concentration of both organic COD loading and VFA was reported in literature for sludge anaerobic

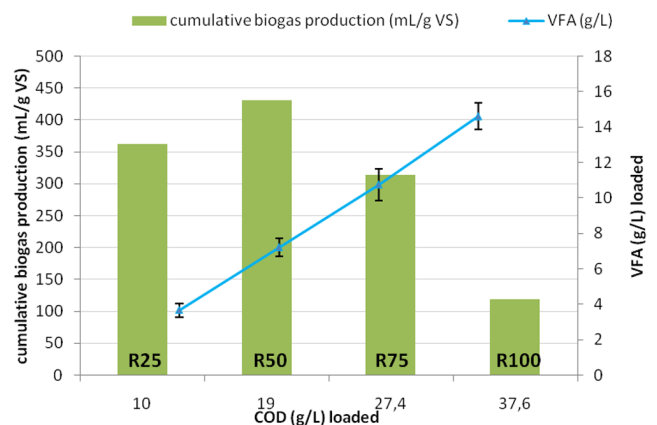


Fig. 2. Cumulative biogas production versus initial COD and VFA concentration.

robic digestion [45] and food waste leachate and sewage sludge mixture [46]. For VFA, it has been reported that toxic threshold depend on the kind of VFA involved and that toxicity can be enhanced significantly by synergism of the individual long-chain fatty acid [44, 47]. In recent work based on food leachate monodigestion and codigestion, the concentration of VFA was in good correlation with the performance of the reactors with values under 4 g/L as optimal concentrations [27]. For the present work, optimal codigestion condition where achieved within initial COD and VFA content range of 11.7 to 32.3 gO₂/L and 2.1 to 7.4 g/L, respectively as illustrated in Fig. 2. In terms of biogas yield this corresponded to a range of 350 to 438 mL/g VS. Biogas yield values closes to these finding were reported by recent works for both food wastes and leachate codigestion with sewage sludge [6, 46]. Results similar to our finding were also reported by [48] for which biogas yield varied from 233 to 344 mL CH₄/g VS for leachate wastewater ratio from 1:9 to 5:5 with maximum yield at 3:7 ratio.

Results of modeling biogas production are reported in Fig. 3 and Table 4. Experimental data of cumulative biogas were best fitted with modified Gompertz model for which R² was around 0.999.

Exploration of modified Gompertz curves showed that leachate dilution improves the biogas potential and reduces the lag phase period of methanogenesis from 25 to 6 d (Table 4).

According to the results obtained, the optimal anaerobic co-digestion conditions both in terms of maximal biogas potential,

Table 4. Key Kinetics Parameters According to Modified Gompertz Model

	R ²	R ²	A: mL/gVS	μ: mL/gVS/d	λ: days
	Exponential	Gompertz	Gompertz	Gompertz	Gompertz
Reactor 25	0.9722	0.9993	372.30	16.71	6.58
Reactor 50	0.9599	0.9996	438.42	16.29	11.64
Reactor 75	0.9605	0.9977	350.59	9.32	15.36
Reactor 100	0.9368	0.9994	120.88	4.13	24.59

λ: lag phase period (days); A: biogas production potential mL/gVS;
μ: maximum biogas production rate mL/gVS.d⁻¹; R²: correlation coefficient

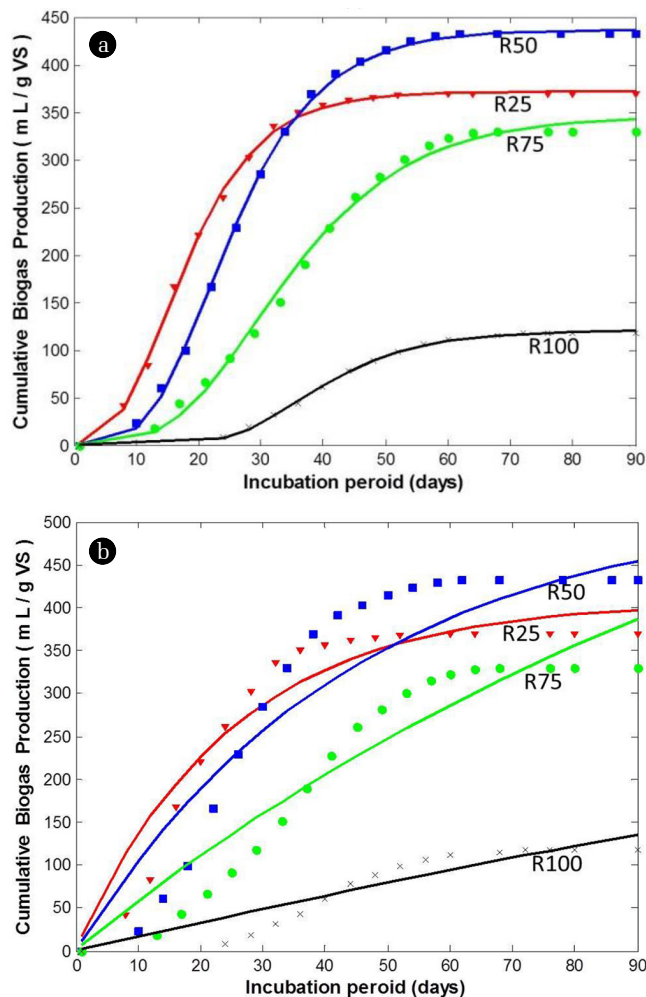


Fig. 3. Cumulative biogas modified Gompertz (a) and Exponential rise to maximum plot (b) where experimental data are given in symbols and simulation plots in lines.

start-up period and maximum daily biogas production rate, could be achieved around leachate volumetric ratios from 25% to 75%. The maximum was recorded at 50%, even though decreasing ratio to 25% had positive effect on time needed to start methanisation and the hydraulic retention time needed to produce 90% of the BMP while increasing ratio over 50% had negative effect on both parameters. The maximum daily biogas production was around 16 mL/g VS for both 25% and 50% ratio but the HRT needed to produce 90% of the BMP was also shorter for the 25% volumetric ratio (31 d versus 41.5 d). Thus, although maximum BMP was recorded at 50% dilution it seems that optimal overall performance and stability of the codigestion could be achieved with more leachate dilution. These findings agree and are close to that of [43] using landfill leachate dilution with synthetic wastewater in the range of 5 to 75% (v/v) for which higher COD removal of over 95% was maintained with leachate addition of 10% and 20% (v/v) while significant decrease of anaerobic treatment efficiency due to inhibition of microbiological activity was observed at leachate concentration above 30% (v/v).

4. Conclusions

The objectives of the present work were to monitor the feasibility of fresh leachate codigestion with wastewater and to evaluate the optimal volumetric ratios that allowed maximal biochemical methane potential. Based on the results obtained, the following conclusions could be highlighted:

- Codigestion of fresh and acid urban waste leachate at wastewater treatment plant is feasible and could increase significantly biogas yield.
- Under batch condition and according to our findings, optimal anaerobic co-digestion conditions both in terms of maximal biogas production, start-up period and the maximum daily biogas production rate could be achieved around initial COD and VFA range of 11.7 to 32.3 gO₂/L and 2.1 to 7.4 g/L, respectively. For the studied leachate this corresponded to a volumetric leachate ratio of 25% to 75% (v/v%).

Further study using semi-continuous anaerobic codigestion conditions is recommended for a better evaluation of codigestion performance.

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