

The best process from energy recovery of the Waste Kitchen university restaurants

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Abstract

This work is part of the perspective of sustainable development and within the framework of the eco-campus project, which avoids the use of energy-intensive treatment processes and is oriented towards extensive rustic processes, we examined the anaerobic treatment process of waste from restaurants of Saleh Bounider Constantine 03 University residences, which generates 737.44 tons of kitchen waste with current student capacity.

The primary objective of this study is to manage this waste, through the use of anaerobic digestion. The biodegradation of crushed kitchen waste was assessed by two routes: anaerobic using the Biochemical Methane Potential test and aerobic using respirometric tests, several parameters to cite the digestion conditions (thermophilic and mesophilic), the Inoculum substrate report were carried out(from 0.5 to 4), as well as the possibility of considering adding paper recovered from waste from the same university to stimulate the system.

The maximum production of methane is obtained for an optimal I / S ratio of 0.5, allowing an energy recovery of 112 mL. g TVS⁻¹ and 416 mL. g TVS⁻¹ of methane for mesophilic and thermophilic respectively, a production which experienced a marked improvement reaching 106.97 and 215.30% after adjustment of pH by adding paper for I / S equal to 3.5 and 4 respectively.

Keys Word: Biodegradability, Anaerobic Digestion, Respirometry, Kitchen Waste, Methanogenic Potential.

I. Introduction

The aim of this study was to evaluate the anaerobic digestion (AD) of kitchen waste from University restaurants Salah Bounider Constantine 3. The success of this process depends on the biodegradability of the substrate used [1]. Indeed, AD tests are basically anaerobic biodegradability tests. However, these require very long residence times [2], which limits the use of this type of test. Therefore, continuous aeration respirometry was used in parallel to possibly find a correlation between the two tests in order to use respirometry as a preliminary test to the AD tests. Biochemical Methane Potential (BMP) test were performed under

mesophilic conditions (37 ° C) and thermophilic conditions (55 ° C).

In order to monitor the effect of AD treatment, it was necessary to characterize the kitchen waste macroscopically by identifying the different foodstuffs on the one hand and to characterize them in terms of pollution parameters (COD, SS, TS, TVS, pH etc.) on the other hand. In addition, the secondary sludge from the local station of **OUED EUTHMANIA** was also characterized as being used as an inoculum in both test series (BMP test and respirometric tests) as well as the characterization of biogas in terms of volume and composition.

II. Materials and methods

II.1. Inoculum

The sludge used in this study comes from the local wastewater treatment plant of OUED EL-EUTHMANIA in Milicity, mainly treating effluents of domestic origin. In order to overcome the residual substrate and to adapt to the conditions of the tests envisaged; sludge samples were post-washed in bottles under anaerobic conditions and at the respective temperatures of the mesophilic and thermophilic conditions for 15 days, in order to promote the growth of anaerobes adapted to the substrate in question and to the respective operating conditions.

II.2. Waste collection

One kilogram of waste was collected in each kitchen of the thirteen university residences located in Constantine University 3, the collected waste will undergo a sorting, quantification and an overall characterization before extracting a representative sample of the waste collected by applying the quarter technique.

II.3. The different measuring devices

The measurement of the biodegradability of waste samples under aerobic conditions was carried out in a respirometer with continuous aeration [03], the tests were carried out for the waste in their solid and leached form. This respirometric technique has the advantage of being applicable to samples of high activity, because the amount of available oxygen will not be limiting, but on the other hand requires a much heavier experimental device.

In this type of respirometry, the determination of total or exogenous respiration must first be preceded by a determination of the transfer coefficient and the endogenous respiration [04].

The mass balance with respect to the oxygen concentration in the liquid phase of the respirometer after injection of a definite amount of substrate will be:

$$\frac{d(VC)}{dt} = Q_e C_e - Q_s C + V_L K_L a (C_s - C) - V_L OUR_T \quad (1)$$

In respirometric cell aerated continuously, the exogenous respiration can be expressed by the following equations [05].

$$\frac{dc}{dt} = K_L a (C_{end} - C) - OUR_{exo} \quad (2)$$

$$OUR_{exo} = K_L a (C_{end} - C) - \frac{dc}{dt} \quad (3)$$

The daily biogas production of each digester was measured by the water displacement method, taking

place in an acidified water column, with the addition of NaCl to avoid the absorption of CO₂. The result obtained is expressed in milliliter per day of biogas produced [6]. On the other hand, the CH₄ content in the biogas was determined by suctioning and injecting a known volume of gas (V₁) produced in a bottle which contains a solution of KOH in the presence of phenolphthalein. This bottle is shaken manually for 3-4 min, so that all CO₂ and H₂S are absorbed in the concentrated KOH solution. The remaining volume of biogas (V₂) is 99.99% of CH₄. It is again aspirated and measured in the biogas measuring device [7].

Liquid phase characterization was undertaken before and after anaerobic digestion period through the determination of pH, total solids (TS), total volatile solids (TVS), Alkalinity (TA) and total alkalinity (TAC), volatile Fatty acids (VFA), chemical oxygen demand (COD), according to Standard Methods [8]. pH was determined using a pH-meter (Jenway 3510 PH meter).

III. Results and discussion

III.1. Preliminary characterization of collected waste and the representative sample

The annual quantity generated by the thirteen university restaurants is 737,444 tons, of which 48.58% is generated in lunch and the rest is generated in dinner, the fraction of the water present in the waste in the form of sauce or other does not exceed 0.32% (W/W), this fraction was displaced by filtration.

The total mass of the representative sample before drying was 218.25 g, it is equal to 68.81 g after drying, the quantity of water entering the composition of the waste represents a percentage of 68.47%, according to [09], the amount of moisture content in the feedstock can have an influence in the anaerobic digestion process and methane yield. A study on the effect of moisture content ranged from 97 to 89% on anaerobic digestion of sludge showed that the amount of methane yield was decreased from 330 to 280 mL/gTVS. Moreover, Chen et al [10] found no significant difference in methane production for the three water contents studied during pretreatment (54%, 70% and 77%) studying the influence of moisture content of solid-state NaOH pretreatment and co-digestion on methane production in the semi-dry anaerobic digestion of rose stalk while for Liotta et al [10]. The experimental results on the effect of total solids content on methane and volatile fatty acid production in anaerobic digestion of food waste show a reduction of the specific final methane yield of 4.3% and 40.8% in semi-dry and dry conditions compared with wet conditions.

The composition of the waste shows that vegetable, egg, meat, bread and other category waste (**Table 1**), which includes scrambled pasta and legumes that are difficult to separate, have percentages greater than 10 % by weight, plastic and aluminum waste consist of yoghurt pots and cheese paper, despite their low levels in the composition of kitchen waste studied, aluminum, plastic and to a lesser extent paper can they are sorted for recovery, representing 1.13%, 1.89% and 0.82% respectively (**Table 1**).

Several studies have proven that food waste is the best biodegradable organic fraction of municipal solid waste from various sources, such as domestic and commercial kitchen waste, cafeterias and restaurants. Since kitchen waste (KW) has a high humidity and easily biodegradable characteristics, anaerobic treatment is preferable to thermal or thermochemical conversion technologies ([11], [12]), as showed in (**Table 2**), the majority organic fraction presents more than 85% of the total fraction, whereas the soluble organic fraction expressed in COD represents only 40.81 % of the

total organic fraction, soluble COD released during pretreatment is more accessible by the anaerobic consortium that can be rapidly converted to biogas[13].

Unfortunately, the representative sample has an acidic pH that is far below the optimal values. For the digestion process, the pH is between 6.5 and 8 [14], and for an optimal operation of the process, it must ideally be between 6.8 and 7.2 [15], but likewise, a good buffering capacity has been recorded since the alkalinity (**Table 2**) is clearly greater than 1000 mg. L⁻¹ CaCO₃[16], this will certainly have an influence on the yields of anaerobic digestion of this waste.

The question asked at this stage this composition will inhibit digestion or not, the prediction of the behavior of this food waste when it comes into contact with the inoculum under anaerobic conditions will be achieved only by preliminary respirometric tests under aerobic conditions.

Table 1. Substrate composition (representative sample of collected Kitchen Waste)

Type of waste	Composition (%)	Amount of water (%)
Chickpea	1,4866	64.92
Vegetables	14,7010	84.25
eggs	12,5206	54.22
Meat	11,1166	57.21
Bread	13,6273	56.39
Cheese	0 ,8093	79.48
Fruit	6,6072	70.72
Paper	0,8259	-
Plastic	1 ,8995	-
Aluminium	1,1397	-
Wood Paper	0 ,8259	-
Other	33,9940	74.10

Table2. Characterization of the substrate (representative sample of collected Kitchen Waste)

parameter	Value
<i>pH</i>	4 ,9
<i>Conductivity(ms/cm)</i>	2,30
<i>TS (mg .L⁻¹)</i>	24484
<i>TVS (mg .L⁻¹)</i>	20889
<i>TA (mg .L⁻¹CaCO₃)</i>	550
<i>TAC (mg .L⁻¹CaCO₃)</i>	3850
<i>COD_T(mg .L⁻¹)</i>	73711,25
<i>CODs(mg .L⁻¹)</i>	30086,25
<i>VFAs(mg .L⁻¹)</i>	3062

III.2. Respirometric Tests

Since its implementation Respirometry has established itself as a robust and less expensive technique, it has been integrated in several areas, include the biodegradability tests ([17], [18]), toxicity tests ([19], [20], [21]) nitrification monitoring [22], Determination of biokinetic constants ([03],[23]) and monitoring of chlorination expansion treatment (proliferation of filamentous bacteria) ([24], [25]).The resulting biodegradability information from respirometric tests established in the context of this study can be used to estimate the biodegradability of these wastes prior to incubation in BMP-Test. that it presents certain characteristics which can be inhibitory of the anaerobic digestion.

The respirometric technique will be used to evaluate the biodegradability of these Kitchen Waste in their lixiviated and solid form in the acclimated and unacclimated state.

III.2.1. Respirometric test of the waste in the leached form

The crushed kitchen waste was brought into contact with the water for four hours, the leachates obtained are carefully analyzed after a coarse filtration, the tests were conducted for doses of the solid waste ranging from 4 to 20 g .L⁻¹.The leachate COD_s obtained ranged from 378.88 mg .L⁻¹ to 1120.88 mg .L⁻¹for the solid substrate tested doses, while the COD_T ranged from 917.618 mg .L⁻¹to 2952.24 mg .L⁻¹for the same doses; leachate obtained all presented an acidic pH (4.52-4.74) whatever the dose put in contact.

Many authors have shown the importance of the initial conditions in the biodegradation tests, more particularly the initial ratio between the substrate and the biomass concentration, designated S_0 / X_0 . This ratio determines the type of respirometric response obtained [26], influences both the metabolic processes involved in the degradation, the identification of kinetic parameters as well as the dissociation of compartments easily and slowly biodegradable. The biodegradability tests were conducted under different initial S_0 / X_0 ratios (0.04, 0.4 and 01 mg COD. mg TVS⁻¹). The respirometric tests will be conducted for the soluble fraction and the total fraction of the leachate.

Maximum respiration reached 22.8, 3.48 and 2.16 mg. L⁻¹.h⁻¹, for the soluble fraction of leachate and for the ratios 0.04, 0.4 and 1 mg COD. mg TVS⁻¹ respectively, close values were recorded for the total fraction of leachate and for same ratios S_0 / X_0 , 22.2, 4.08 and 1.88 mg. L⁻¹.h⁻¹, but requiring more time to degrade this fraction, the degradation time reached more than 09 hours for an initial ratio S_0 / X_0 equal to 01mg COD. mg TVS⁻¹(**Table 3**).It has been noticed that maximal respiration decreases while increasing the initial imposed ratios, this can only be explained by the predominance of microbial synthesis with respect to respiration while increasing this ratio.This predominance is clearly visualized in the respirogram obtained for an initial ratio S_0 / X_0 equal to 01, since the return to the initial endogenous state did not take place, a difference between the value of the initial endogenous respiration before the injection of the substrate and endogenous respiration after injection of the substrate is recorded (very apparent in the total fractions) (**Figure 1**).

Table 3. Parameters for identifying the respirometric responses obtained for the various initial reports S_0 / X_0 for the soluble and total fraction of the leachate from kitchen waste

Kitchen Waste Leachate	Soluble fraction			Total Fraction		
S_0/X_0 (mg COD. mg TVS ⁻¹)	0.04	0.4	1	0.04	0.4	1
C_{end} (mg. L ⁻¹)	6.5	8.11	8.52	7.2	8.44	8.02
$K_L a$ (Min ⁻¹)	0.1	0.20	0.071	0.05	0.042	0.031
$OUR_{exo_{max}}$ (mg. L ⁻¹ .h ⁻¹)	22.8	3.48	2.16	22.2	4.08	1.88
The amount of oxygen consumed (mgO ₂ . L ⁻¹)	4.24	7.63	12.042	11.02	11.83	15.70
Degradation time (min)	14	32.5	400	37.5	325	550

For total fraction kitchen waste leachate, the amount of oxygen consumed is almost constant even increasing the ratio of 10 (passing from a ratio of 0.04 to 0.4)(Table 3), against the degradation time is eight times higher. The times required for the reduction of the injected substrates in the soluble form are less important because of the nature of the injected substrate not requiring a hydrolysis step to be degraded (Figure 1).

The leachates from kitchen waste showed good biodegradability for all the reports tested, despite the acidic nature of leachates, biodegradability is still obtained even for the high ratio tested (S_0 / X_0 equals 01), on the contrary a microbial growth was recorded for this report, the two ratios 0.4 and 01 will be tested in digestion (I / S equal to 2.5 and 01 mg TVS. mg COD⁻¹ respectively).

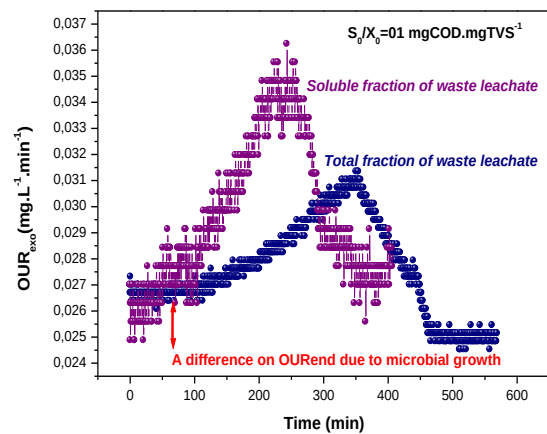
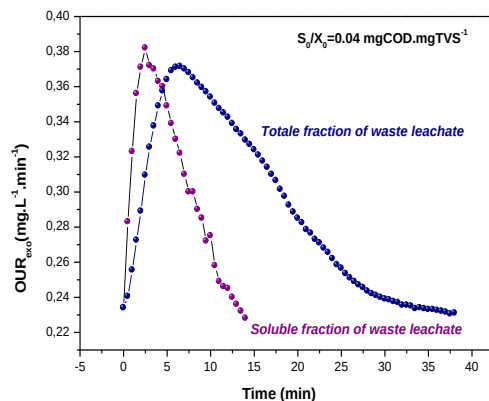


Figure 1. Respirogrammes obtained after injections of the total and the soluble fraction of waste leachate (example of two different ratios S_0 / X_0)

III.2.2. Respirometric test of the waste in its solid form

Before carrying out the respirometric tests of the waste, a step of adaptation to kitchen waste (solid form) seems to be necessary (adaptation to high concentrations). A perfectly stirred reactor was used to adapt the microorganisms to the kitchen waste, progressive additions of solid waste crushed are injected into the reactor, from a concentration of 4 g.L⁻¹ to a concentration of 20 g.L⁻¹, with a step of 4 g.L⁻¹(Figure 2).

The microorganisms seem to be well adapted to the waste, the abatement efficiencies of the carbon load expressed in COD_T are almost constant; varies between 58.45% and 66.18%(Figure2), corresponding to an increase in the biomass of 13.16 to 28.05 g.L⁻¹ of TS, a series of

microscopic visualizations were carried out in the fresh and colored state, which reflect a good state of flocculation with total absence of the filaments, the duration of 3 days seems to be adequate to gradually adapt the microorganisms to the heavy loads

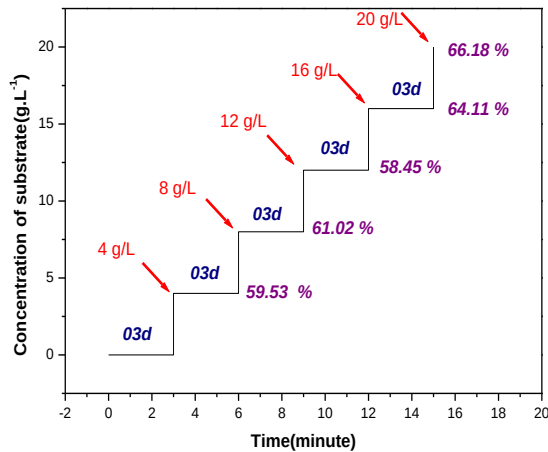


Figure 2. Program for injecting kitchen waste in solid form into the adaptation reactor

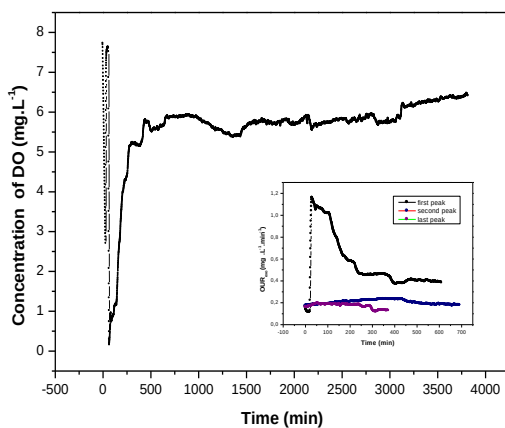


Figure 3. Temporal evolution of dissolved oxygen concentration and Respirogrammes obtained after solid substrate injections (S_0 / X_0 : 0.4mg COD .mg TVS⁻¹)

III.3. Anaerobic digestion of kitchen waste (Discontinuous system)

As pointed out in the introduction, the objectives of this study are to evaluate the biodegradability of this waste and its methanogenic potential by considering the mesophilic and thermophilic conditions.

Samples of crushed solid waste of different concentrations were placed in bottles (BMT-Test) in the presence of the inoculum in addition to a sample composed only of sludge (inoculum), the different reactors are placed in an incubator at a temperature 37 ° C (mesophilic phase) and 55 ° C (thermophilic phase).

III.3.1. The production of biogas

The cumulative volumes of biogas produced during the process of digestion of substrates at different ratios (I / S) for mesophilic and thermophilic conditions are presented respectively in **Figure 4** and **5**.

The ratio R6 (I / S = 3) and R7 (I / S = 3.5) in mesophilic conditions showed a malfunction, that's why the results of these tests were eliminated. For the same conditions, the production of biogas starts from the first day and the quantity of production for the different ratios differs, the highest value is obtained for the ratio R2 with 50mL. g TVS⁻¹ and the smallest corresponds to the ratio R8 with 10 mL. g TVS⁻¹. The amount of biogas begins to increase gradually from the second day until the 4th day for R8, R5. Then, the production stabilizes, this is explained by the lowering of the pH and the increase of the production of the VFA. Concerning R2 and R3 the increase will continue until the 9th day and stabilizes.

It is noted that the increase in the production of R1 is perceptible and constant 160 mL. gTVS⁻¹. Indeed, the I / S ratio of 0.5 gave the best results of specific production of biogas which can be explained by an exponential microbial growth favored by the fact that the concentration of the substrate is relatively important compared to the concentration of the initial biomass.

In thermophilic conditions, the production of biogas is much greater than that in mesophilic conditions. It can be seen that for the ratio R1 (I / S = 0.5) the production of biogas is instantaneous and rapid compared to other reports, or there was a complete stoppage of production after the 5th day. In the case of anaerobic digestion in thermophilic phase, degradation of organic matter is faster and therefore more volatile fatty acids (VFA) generated which causes a rapid drop in pH and inhibition of methanogens. For the ratios of R4 (I / S = 2) up to R8 (I / S = 4), there is a complete halt in the production of biogas, so for batch with a large amount of waste, the anaerobic digestion is completely inhibited in both thermophilic and mesophilic phases.

For R2 (I / S = 1) and R3 (I / S = 1.5), specific biogas production curves with more exponential phases are observed. Except that for R2, there is an

increase in production after the 22nd day that can be attributed to the restoration of the anaerobic system and the return to production.

The cumulative specific volume production of biogas from food waste after the 35th day of

incubation for the ratio R1 (I / S = 0.5) was 495.38 mL. g TVS⁻¹, in the thermophilic phase and was 156.39 mL. g TVS⁻¹ in phase mesophilic for the same ratio, a production increase of 216.75% was achieved only by changing the incubation temperature.

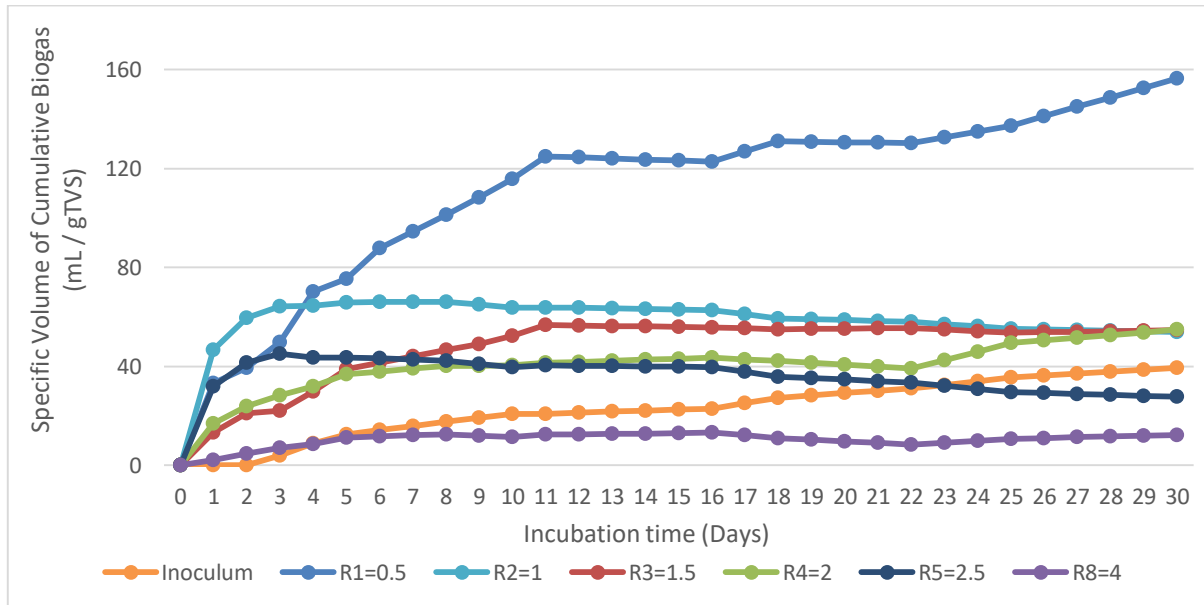


Figure4. Cumulative production of the specific biogas in mL. g TVS⁻¹ for the various I / S ratios tested in the mesophilic phase

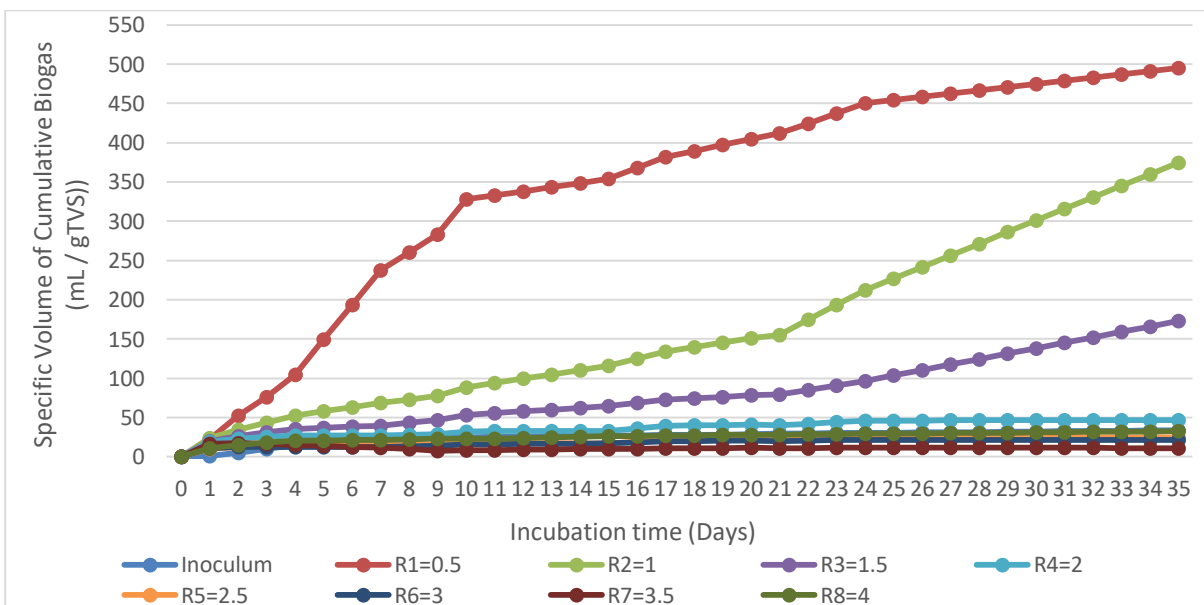


Figure 5. Cumulative production of the specific biogas in mL. g TVS⁻¹ for the various I / S ratios tested in the thermophilic phase

III.3.2. Composition of the biogas produced

The volume of methane produced at the end of the experiments is presented in **Figure 6**, In mesophilic conditions, the percentage of methane in the biogas produced for the ratio R1 is 70% and for the ratios

R2 and R3 the percentages are 55% and 40% respectively. The amount of methane begins, gradually decrease until reaching a value of 20%. Likewise, for the other remaining samples (R4, R5, and R8) did not give a large amount of methane because of the strong presence of pH inhibitors and VFAs accumulation, as known food waste contains higher levels of organic materials, such as starches,

proteins, and lipids; accordingly, it may become a plentiful source of inexpensive organic substrate for fermentative VFAs production, Chen et al.[10] and Bong et al. [27] explained that the chances of VFAs inhibition increased following an increased proportion of food waste in the AD system, a VFAs concentration of more than 5000 mg.L⁻¹ may cause inhibition of digester [28].

Similarly, in thermophilic conditions, it is noted that the ratio R2, R3 give a percentage of 64% and 51% respectively of methane with a percentage of 80% for the ratio R1. The amount of methane begins, gradually decrease for R3, R4 until reaching a value of 42%.

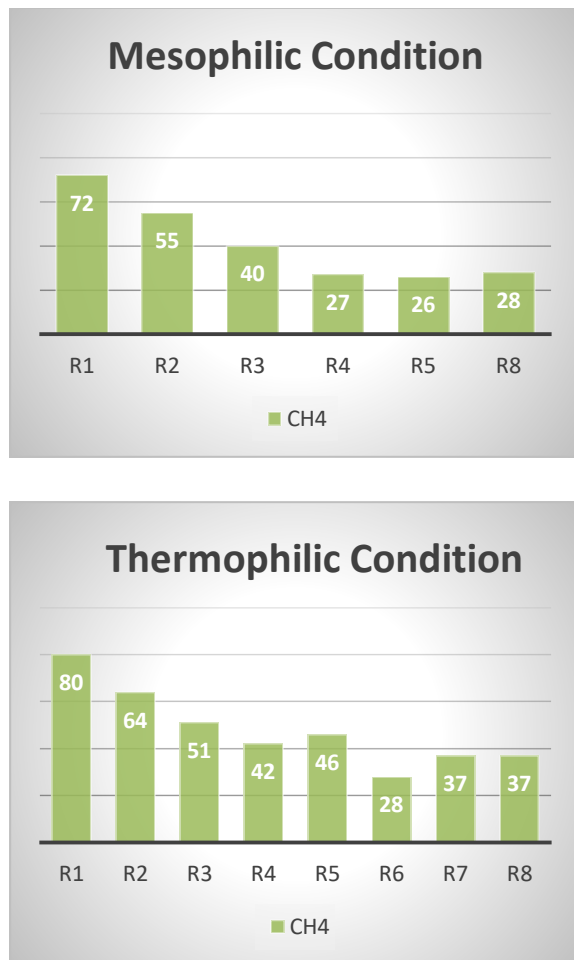


Figure 6. Biogas composition (%) produced in mesophilic and thermophilic conditions

III.3.3. Effect of pH adjustment on biogas production

Since the optimum production of biogas by food waste was in the thermophilic phase, this test was repeated with the two small ratios (R1 = 0.5 and R2 = 1) and the large ratios (R3 = 3.5 and R4 = 4) in order to see the effect of adjusting the pH on the yield of biogas production. **Figure 7** represents the specific production of biogas accumulated after the adjustment of the pH in the thermophilic phase in the different ratios.

First, a higher latency phase was recorded, since the source of the sludge used as an inoculum is the adaptation reactor used in respirometric studies, where the biomass has been acclimated to the substrate but not acclimated to the operating conditions (temperature, anaerobic condition).

A drop in pH due to the accumulation of VFAs has been recorded. To adjust the pH a rejection of papers was used as a buffer solution with a pH = 8.2. Then the batches were bubbled with nitrogen to re-establish the anaerobic conditions, this procedure was applied daily. A positive effect was recorded on the production of biogas, where we notice increases in production after adjusting the pH. The cumulative specific volumes of biogas were 571.85; 351.64; 118.07; and 103.01 mL. g TVS⁻¹ for R1, R2, R3, and R4 respectively. Comparing with the results of the previous thermophilic part, a significant increase in production is recorded for all the reports tested, the most significant of which are those of reports R3 and R4, where without adjustment of pH the production of biogas was 45.07 and 32.67 mL. g TVS⁻¹ respectively. Either increases of 106.97 and 215.30% in production, which is encouraging to also recover this waste paper in anaerobic way since this type of waste exists in abundance in the university.

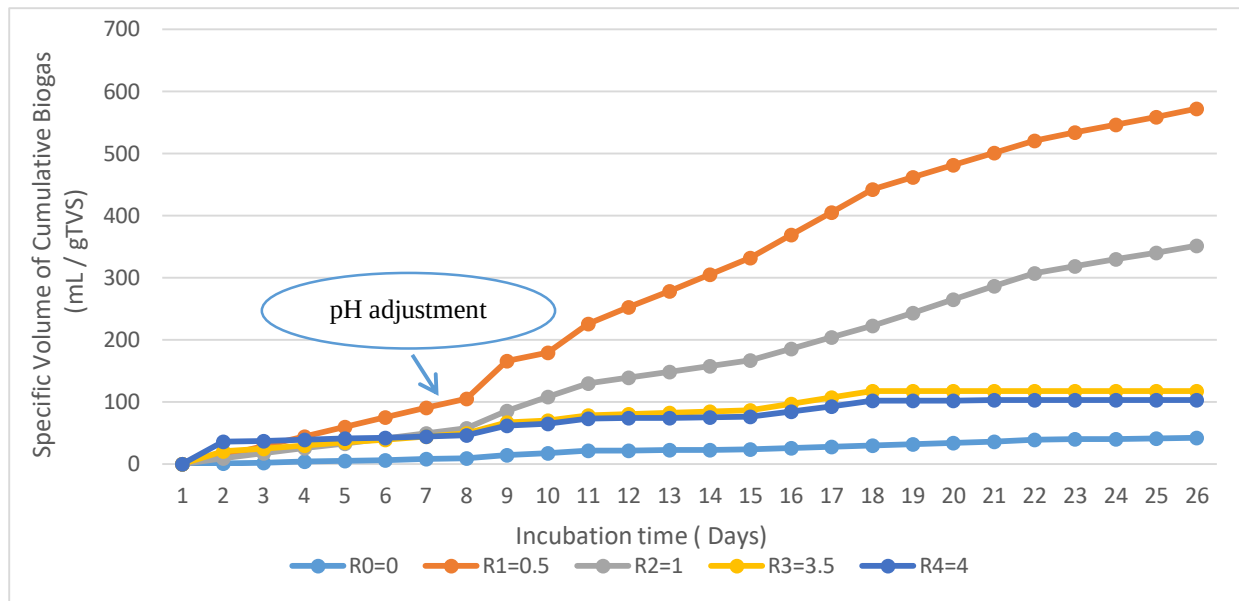


Figure 7. Cumulative production of the specific biogas after treatment and pH adjustment in the thermophilic condition

IV. Conclusion

At the end of this study, it is important to recall the main results obtained with regard to Kitchen Waste (KW). The characterization made it possible to determine the KW profile of University restaurants Constantine 3, KW After crushing, the waste solution was characterized by considering total and soluble COD, TS and TVS, TA and TAC, VFA, pH and conductivity. The results showed that the waste was at approximately 32% solids and are considered to be loaded with COD.

The prediction of the biodegradability of this waste was tested by continuous aeration respiration in the state of soluble and total leached and in the solid state with the biomass in the acclimated state and not acclimated, this technique has shown how a fast and efficient prediction technique before starting the biodegradation tests under anaerobic conditions.

The results obtained showed the importance of the ratio Inoculum on substrate in the biogas production and the elimination of the COD. The optimal I / S ratio was 0.5 with a maximum biogas production of 160 mL. g TVS⁻¹, for mesophilic conditions, of which 70% is methane. For thermophilic conditions, the maximum production of biogas was 520 mL. g TVS⁻¹, of which 80% is methane. Elimination of soluble COD was for the thermophilic conditions of 96%. Some tests exhibited very low biogas production, which led us to consider adding paper to increase the alkalinity of the system.

The KW if they are used in the production of methane would have produced 104000 m³. Kg⁻¹. y⁻¹ in mesophilic phase and 391000 m³. Kg⁻¹. y⁻¹ in

thermophilic phase, equivalent to annual electrical production of 592800 and 2228700 KWh. Kg⁻¹. y⁻¹ respectively in mesophilic and thermophilic condition. This production can be improved by using other pretreatment other than the mechanical pretreatment deployed in this study (crushing).

The paper recovered from the discharges of the faculties of the university with its various administrative and educational institutions can be a possible and an important source allowing not only for the regularization of the pH but also for the contribution to the production of biogas.

Respirometry tests can also be used as preliminary tests before beginning anaerobic digestion for reconstitution of waste giving better biodegradability, the removal of waste may be inhibitory or to test pretreatments that can improve digestion yields.

Acknowledgment

The authors would like to thank infinitely all the managers of university kitchens at Salah Bounider University, Constantine 3, for their quantification and sampling efforts.

V. Nomenclature

AD :Anaerobic Digestion	TAC : Full Alkalimetry titer (mg CaCO ₃ .L ⁻¹)
KW : Kitchen Waste	TA : Alkalimetrictiter(mg CaCO ₃ .L ⁻¹)
DO :Dissolved Oxygen	BMT-Test : Biochemical Methane Potential test
VFA : Volatile Fatty Acid (mg.L ⁻¹)	C₀ : The concentration of oxygen in the liquid phase(mg.L ⁻¹)
COD :Chemical Oxygen Demand (mg.L ⁻¹)	C_s : The concentration of oxygen saturation in the liquid phase(mg.L ⁻¹)
COD_s :SolubleChemical Oxygen Demand (mg.L ⁻¹)	C_{end} : The concentration of oxygen in the liquid phase in the endogenous state(mg.L ⁻¹)
COD_r :TotalChemical Oxygen Demand (mg.L ⁻¹)	K_{La} : Oxygen transfer coefficient (min ⁻¹)
TS :Total solids contained in waste or sludge (mg. L ⁻¹)	OUR_T :Total oxygen uptake rate (mg O ₂ L ⁻¹ min ⁻¹)
TVS :Volatile total solids contained in waste or sludge (mg. L ⁻¹)	OUR : Exoexogenous oxygen uptake rate (mg O ₂ L ⁻¹ min ⁻¹)

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