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## Article

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# Mesophilic anaerobic digestion of food waste: Effect of thermal pretreatment on improvement of anaerobic digestion process

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## Abstract

The treatment of food waste (FW) is an important challenge in developed and undeveloped countries due to the rapid disintegration of this waste. Hence biogas technology is used to produce energy and to reduce the volume of waste. This technology has disadvantages in terms of sensitivity to nutritional imbalance and low biodegradability. In this case, several pretreatments have been applied to improve biogas production such as thermal pretreatment (TP). This study investigated the effects of TP on physico-chemical properties and methane yield (MY) improvement. With the effect of temperature and time treatment, soluble COD was increased and reaching  $68.54 \pm 2,4$  mg/L recorded at (100 ° C, 30 min), which was 43. 41% higher than control. In contrast, TP decreased the percentage of VS compared to the raw FW. Furthermore, anaerobic digestion (AD) of FW pretreated at 100 ° C during 30min was tested, the MY was (382.82 mLSTP CH<sub>4</sub>/ g VS) which 23.68 % higher than untreated food waste. Biodegradability was increased from  $83.2 \pm 3$  % to  $91.4 \pm 4.1$  % showing an increase of 9.8 %.

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**Keywords:** Anaerobic digestion; Food waste; Methane; Thermal pretreatment; Biogas

## 1. Introduction

The quantity of FW generated in many sectors (households, hotels, supermarkets, restaurants. . . ) increased with the economic development and demographic growth in Morocco. Mismanagement without any efficient treatment of this waste involves environmental risks in terms of greenhouse gas emission and organic pollution. The AD is one of the most viable treatments for organic FW since it combines the treatment of waste and production of biogas as renewable energy [1]. The AD is natural biodegradation of organic matter by various populations of microorganisms in the absence of oxygen. This biodegradation produces biogas, mainly composed of methane and carbon dioxide. The main components of FW are carbohydrates, lipids and proteins [2]. The soluble organics are

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rapidly converted by hydrolysis into simple sugars and then fermented into VFA (volatile fatty acid). Moreover, the complex organic compounds of FW, such as lipids from animal fats, vegetable oils and large-molecular-weight carbohydrates are difficult to biodegrade, making the hydrolysis a limiting step in AD of FW [3]. To enhance the AD process, in terms of biodegradability and biogas production, several pretreatment techniques have been developed: biological, mechanical, thermal and chemical treatments [4]. These techniques increase the solubilization of organic matter and refractory compounds, leading to the reduction of organic matter, which increase biogas production. Among these methods, TP has been widely used to improve FW anaerobic digestion [5]. In fact, TP disintegrates cell membranes and facilitates the dissolution of recalcitrant organic compounds, which promote the hydrolysis of macromolecule over a specific time and temperature conditions [6]. Generally, most of the studies reported that the optimal temperature for TP is in the range 110 and 180 °C and treatment time from 20 to 60 min [7]. Jingxing et al. evaluated the effect of heat pretreatment of FW by autoclave, under conditions (120 °C, 1 bar) for 30 min, they obtained a 13% increase in COD and methane production was 48% higher compared to the control test [8]. The optimal temperature and duration of pretreatment remain difficult to determine, they depend on the type of substrates and conditions of anaerobic digestion. This research study aimed to investigate and evaluate the effects of TP on physico-chemical properties by applying different temperatures and time treatments using FW as substrate to determine the optimal range of TP. Anaerobic digestion was carried out in CSTR digester working in semi continuous mode at mesophilic conditions. Moreover, MY, biodegradability, allowed OLR and process stability were determined in order to have a deep understanding of the TP effects.

## 2. Materials and methods

### 2.1. Substrate and inoculum

The FW used in this study was obtained from the university restaurant (IBN Tofail University, Kenitra, Morocco). To have a representative sample, a statistical study on the amount of waste generated was done, daily 20 waste from the meals served were weighed during one month. The results of this study allowed us to determine the percentage of each constituent element of the substrate. The FW had crushed and homogenized using an electric mixer and stored in at 4 °C. Moreover, the inoculum used comes from a pilot digester treating wastewater sludge.

### 2.2. Experimental set-up

The experimental set-up used for the AD consisted of two 1L Pyrex completely mixed reactors working parallel. It worked in semi continuous mode. The digesters are equipped with four openings for biogas ventilation, inject nitrogen gas to maintain anaerobic conditions, take samples and load feedstock. A magnetic stirrer ensures the mixing of the digesters content and the mesophilic conditions were maintained using a thermostatic jacket containing glycerol and water heated at 37 °C. For separation of the produced biogas, hermetically sealed bubblers containing NaOH (6N) solution connected between the two elements. The volume of methane displaced is equal to the volume of water measured from the reservoir with the temperature and pressure correction to standard conditions (0 °C, 1 atm) [9].

### 2.3. Thermal pretreatment

The TP was carried out in an oven (LABTECH, LEF-105P-1, Korea). Three different temperatures were tested (60, 80, and 100 °C) during different times (15, 30 and 45 min). In order to determine the soluble chemical oxygen demand (CODs), the substrates pretreated were centrifuged at 5000 rpm for 5 min then the supernatant was filtered and analyzed. Optimal TP conditions were determined as the highest solubilization rate obtained after TP. The solubilization rate was calculated by the following relation:

$$\text{Sol (\%)} = ((\text{COD}_{\text{Safter TP}} - \text{COD}_{\text{Sbefore TP}}) / \text{COD}_{\text{Sbefore TP}}) * 100$$

## 2.4. Experimental procedure

To achieve the bio-stimulate of biomass prior to the experiments, the mesophilic anaerobic reactors were initially loaded with 7 g SV/L of granular sludge as inoculum. Once the adaptation was carried out, the organic load added to the digesters was continuously increased from 0.5 gVS/L to 4 gVS/L of a substrate at interval of 0.5 g VS/L. During each case, the load was carried out in triplicate and the volume of methane produced was measured and the samples were taken for analysis before and after feeding. All analyses in this study was carried out in triplicate and as per standard methods of American public health association APHA [10].

## 3. Results and discussion

### 3.1. Characterization of FW and inoculum

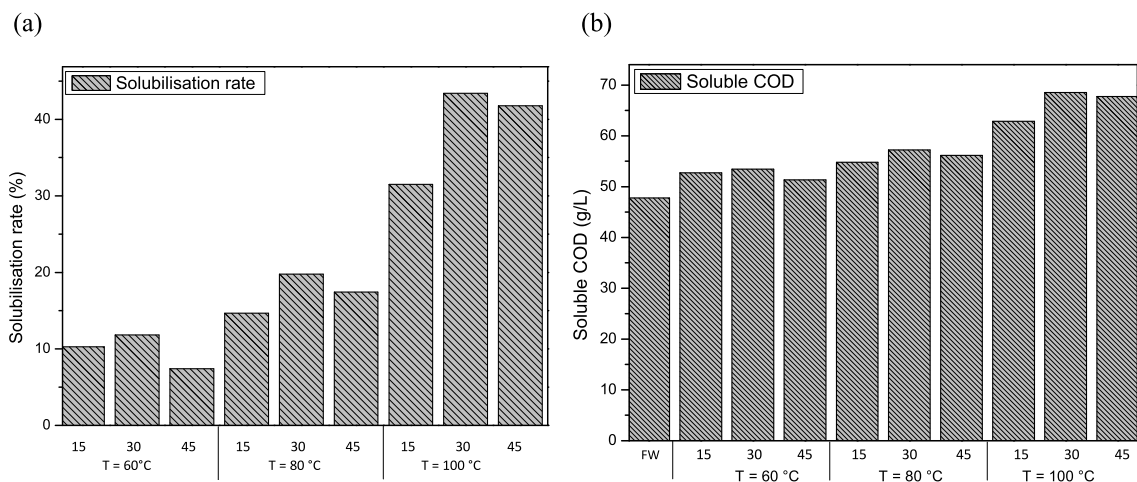
Physico-chemical characteristics are important parameters to design and operate biogas plant because they have a direct effect in AD process. The characteristics of FW used as substrate are illustrated in Table 1, it can be observed that the percentage of VS in TS was 92.1 indicating that FW has a high organic matter content, which makes FW as substrate is a suitable candidate for anaerobic digestion.

**Table 1.** Physico-chemical characterization of FW and inoculum.

Parameter	FW	Inoculum
pH	4.7 ± 0.2	6.2 ± 0.4
TS (% wet basis)	16.5 ± 0.3	2.8 ± 0.2
VS (% wet basis)	15.2 ± 0.7	1.7 ± 0.5
VS (% TS)	92.1	60.7
COD <sub>s</sub> (g/L)	47.7 ± 1.7	ND
VFA (g acetic acid/L)	5.8 ± 2.3	ND
ALK (mg CaCO <sub>3</sub> /L)	3.7 ± 0.5	ND
TKN (g/kg)	3.2 ± 0.6	ND

### 3.2. Effects of thermal pretreatment on physico-chemical properties

In order to investigate the effects of TP on physico-chemical properties and AD performance, at different temperatures and treatment duration, the solubilization rate, CODs, and VS were evaluated before and after TP and the results are shown in fig.1. The soluble organic matter consisting mainly of dissolved matter, its concentration can be characterized by CODs, because CODs and temperature have direct correlation and effect on process performances. Fig. 1(b) shows the variation of CODs in each temperature and time treatment. As it can be seen,



**Fig. 1.** (a) solubilization rate as function of TP parameters after pretreatment; (b) soluble COD before and after pretreatment.

the CODs for all pretreatments conditions was higher than control, this is due to the breakdown of chemical bonds caused by temperature such as the degradation of proteins, polysaccharides, and carbohydrates contained in FW, which causes the release of organics in liquid phase. At a temperature of 60 °C and 80 °C, the maximum CODs values recorded at a treatment time of 30 min were  $53.4 \pm 2,3$  and  $57.24 \pm 1,7$  mg/L reaching a solubilization rate of 11.8% and 19.77% (Fig. 1(a)) respectively. However, these values were lower than those recorded during pretreatment at 100 °C, the maximum value was  $68.54 \pm 2,4$  mg/L at 30 min with a solubilization rate of 43.41%. This difference on CODs is due to the uncompleted disintegration of macromolecules contained in FW when the substrates were treated at temperature lower than 100 °C, which reduced their release in a liquid phase. Moreover, the enhancement of CODs has shown that the TP had a positive effect which can improve methane production because the release of organics in a liquid phase makes it more accessible for bacteria. Therefore, the TP at 100 °C for 30 min was chosen for AD optimal performances.

### 3.3. Process stability

The stability of the process was evaluated by monitoring the pH, VFA and VFA/ALK ratio in the effluent of digesters at the end of each added load. Fig. 2(a) shows the VFA evolution throughout the added load for treated and untreated FW. For treated FW, the concentration of VFA was quite constant until the load 3 g VS/L reaching a value of  $753 \pm 17.0$  mg acetic acid/L, the highest value was  $1398 \pm 24$  mg acetic acid/L recorded at the load 4 g VS/L. Contrariwise, VFA concentration of untreated FW began to rise from the load 1.5 g VS/L ( $358 \pm 22$  mg acetic acid/L) and reaching the maximum value of  $1149 \pm 31$  mg acetic acid/L at 4 g VS/L. The rise up of VFA concentration with the increase of added load is due to the accumulation of VFA at high organic load and result in decrease of pH [11]. However, the process was stable even at high load as shown in Fig. 2(b), the VFA/ALK ratio varied between 0.09 and 0.14, this range was lower than 0.40 established in the literature as the inhibition thresholds might because an excessive concentration of VFA and lead to process acidification. Further, the pH varied between  $7.29 \pm 0.31$  and  $7.76 \pm 0.12$  with a mean value of  $7.6 \pm 0.21$ , these values were in the range of 7.3 to 7.8 defined in the literature as the optimal range to avoid a disturbance in the methanogenic activity [12].

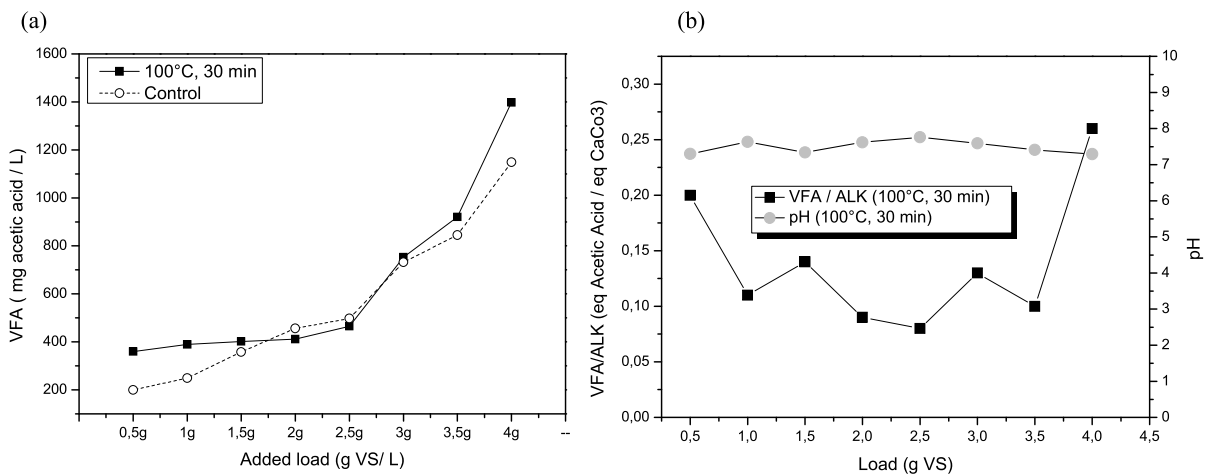


Fig. 2. (a) variation of VFA; (b) Evolution of pH and VFA/ALK ratio against the added load during AD of FW treated at (100 °C, 30 min).

### 3.4. Methane yield and biodegradability

In order to investigate the effect of TP on MT, the MY was calculated by adjusting the pairs of maximum experimental volume and methane produced volume during each added load to a straight line of linear regression. The Fig. 3 represent the MY of treated and untreated FW respectively against the added load. The MY of untreated FW was  $309.52 \text{ mL}_{\text{STP}} \text{ CH}_4/\text{g VS}$ , this value was lower than those obtained by Ariunbaatar et al. [3], they found a

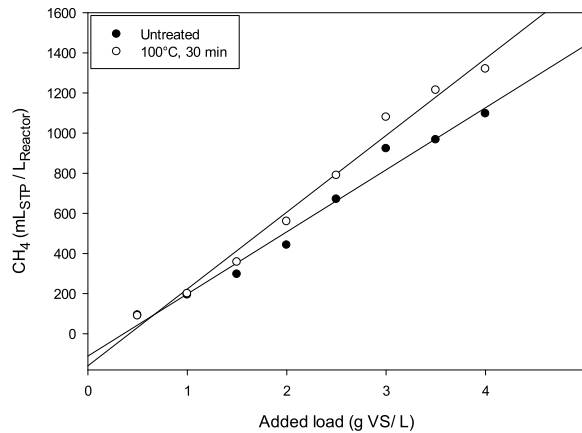


Fig. 3. Variation of experimental methane volume produced against the added load.

value of specific methane yield ( $426.0 \pm 8.5$  mL CH<sub>4</sub>/g VS) during a batch test of FW under mesophilic conditions. Furthermore, the MY of treated FW was 382.82 showing an increase of 23.68% compared to the untreated FW. The Same results was observed by Naran et al. [13], by applying an autoclave pretreatment for FW at (120 °C, 60 min), the methane production was increased 32.3% than control. These results indicate that TP improves the methane production due to the deflocculation of macromolecule resulting in increase of surface area which favors the contact between substrate and micro-organisms [14,15]. On the other hand, biodegradability is one of fundamental parameters that was determined in this study to evaluate the effect of TP. Biodegradability is defined as the VS removed during AD compared to the VS added. For treated and untreated FW, the biodegradability was ( $83.2 \pm 3\%$ ,  $91.4 \pm 4.1\%$ ), which shows an increase of 9.8%. These results are in accordance with the increase of MY, high biodegradability result in high MY, which proves that TP has a positive effect on AD of FW.

### 3.5. Organic loading rate

The organic loading rate (OLR) is an essential operational parameter for large-scale AD applications. OLR is defined as the amount of substrate to be added with the digester volume and time. In this case, the OLR was calculated considering the time required to reach 95% of maximal methane production, and the results is shown in Fig. 4. It can be seen that the OLR increased from 1.42 to 2.10 kgVS/m<sup>3</sup>.d for untreated, and 1.46 to 2.53 kgVS/m<sup>3</sup>.d for treated FW. This values of OLR increased with the increase of added load until the load 2 kg VS/m<sup>3</sup> and 2.5 kg

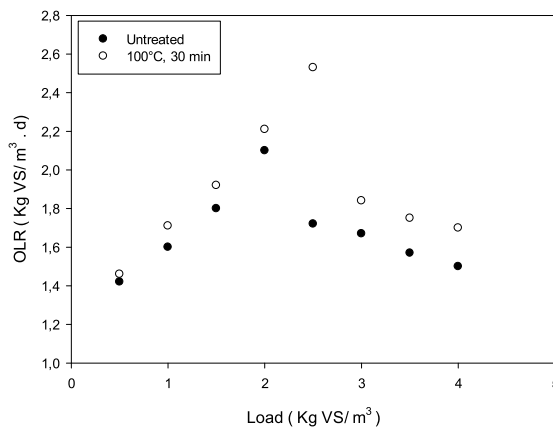


Fig. 4. Evolution of OLR against the Load for untreated and treated FW.

VS/ m<sup>3</sup> for untreated and treated FW respectively, which indicate that with the TP the digester can treat organic load higher than without pretreatment. These results were in the line with those founded by Tampio et al. [11] who found that the maximum MY was observed at OLR of 3 kgVS/m<sup>3</sup> for untreated FW and 4 kgVS/m<sup>3</sup> for autoclaved FW at mesophilic conditions.

#### 4. Conclusion

Regarding the results obtained through this study in which the effects of TP in terms of solubilization rate, CODs and MY were investigated. We can conclude that:

- CODs increased with temperature increase reaching the maximum value of  $68.54 \pm 2,4$  mg/L at a treatment temperature of 100 °C for 30 min.
- The solubilization rate in terms of CODs increased by 43.41%
- MY of FW pretreated at 100 °C for 30 min was 382.82 mL<sub>STP</sub> CH<sub>4</sub>/g VS showing an improvement of 23.68% compared to the control
- The AD process was stable and the allowed OLR was 2.53 kgVS/m<sup>3</sup>.d, while the control was 2.1 kgVS/m<sup>3</sup>.d

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#### References

- [1] Stabnikova O, Liu XY, Wang JY. Digestion of frozen/thawed food waste in the hybrid anaerobic solid–liquid system. *Waste Manag* 2007;28(9):1654–9.
- [2] Wang K, Yin J, Shen D, Li N. Optimisation of the anaerobic digestion of agricultural resources. *Bioresour Technol* 2014;99(17):7928–40.
- [3] Ariunbaatar J, Panico A, Frunzo L, Esposito G, Lens PN, Pirozzi F. Enhanced anaerobic digestion of food waste by thermal and ozonation pretreatment methods. *J Environ Manag* 2014;146:142–9.
- [4] Carrèrea H, Rafrafi Y, Battimelli A, Torrijos M, Delgenes JP, Ruysschaert G. Methane potential of activated sludge and fatty residue: Impact of co-digestion and alkaline pretreatments. *Open Environ Eng J* 2010;3:71–6.
- [5] Carlsson M, Lagerkvist A, Morgan-Sagastume F. The effects of substrate pretreatment on anaerobic digestion systems: a review. *Waste Manag* 2012;32:1634–50.
- [6] Chen T. Effect of hydrothermal treatment on the levels of selected indigenous microbes in food waste. *J Environ Manag* 2012;106:17–21.
- [7] Deepanraj B, Sivasubramanian V, Jayaraj S. Effect of substrate pretreatment on biogas production through anaerobic digestion of food waste. *Int J Hydrogen Energy* 2017;42–42:26522–8.
- [8] Jingxing M, Duong TH, Smits M, Verstraete W, Carballa M. Enhanced biomethanation of kitchen waste by different pre- treatments. *Bioresour Technol* 2011;102:592–9.
- [9] Belhadj S, Joute Y, El Bari H, Serrano A, Gil A, Siles AJ, Chica AF, Martín MA. Evaluation of the anaerobic co-digestion of sewage sludge and tomato waste at mesophilic temperature. *Appl Biochem Biotechnol* 2014;172:3862–74.
- [10] American Public Health Association. Standard methods for examination of water and wastewater. 17th ed. Washington (DC): 1989.
- [11] Tampio E, Ervasti S, Paavola T, Heaven S, Banks C, Rintala J. Anaerobic digestion of autoclaved and untreated food waste. *Waste Manag* 2014;34:370–7.
- [12] Wheatley A. Anaerobic digestion: A waste treatment technology. London: Elsevier; 1990.
- [13] Naran E, Toor UA, Kim DJ. Effect of pretreatment and anaerobic co-digestion of food waste and waste activated sludge on stabilization and methane production. *Biodegradation* 2016;113:17–21.
- [14] Eskicioglu C, Kennedy KJ, Droste RL. Characterization of soluble organic matter of waste activated sludge before and after thermal pretreatment. *Water Resour* 2006;40:3725–36.
- [15] Protot A, Julien L, Christophe D, Partick L. Sludge disintegration during heat treatment at low temperature: a better understanding of involved mechanisms with a multi-parametric approach. *Biochem Eng J* 2011;54:178–84.