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## Article

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# Effect of combined mechanical–ultrasonic pretreatment on mesophilic anaerobic digestion of household organic waste fraction in Morocco

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## Abstract

Methanization is a technology that involves complex biological reactions and it is the subject of several scientific studies. The paper aims to evaluate the effect of the combined mechanical and ultrasonic pretreatment (CMUP) on the anaerobic digestion (AD) of the household organic waste fraction in Morocco (HOWF), using a continuous stirred tank reactor (CSTR) at mesophilic conditions.

This article presents and compares a results obtained by operating two experiments in lab scale reactors with mechanical pretreatment (MP) and with CMUP. The experiment with MP was considered in this study as a control. During the handling period, the effect of CMUP on the AD of HOWF was studied. The process was evaluated in terms of methane production and biodegradability. The stability was maintained within correct parameters throughout the process for each experiment, while the methane yield and biodegradability of the control and CMUP experiments were 382 (mL CH<sub>4</sub> g<sup>-1</sup>VS) (0 °C, 1 atm), 72%, and 493 (mL CH<sub>4</sub> g<sup>-1</sup>VS) (0 °C, 1 atm), 86 % respectively. This shows clearly that the CMUP enhance the methane production and increase the biodegradability, suggesting that this combination pretreatment improve the hydrolysis and methanogenesis phases of the process.

A kinetic study on anaerobic digestion results using the first order model was also used. The mathematical model shows a good fit with the experimental data.

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**Keywords:** Anaerobic digestion; HOWF; Mechanical pretreatment; Ultrasonic pretreatment; Methane yield; Biodegradability

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## Nomenclature

VS	Volatile Solids
Mp	Methanogenic potential (N mLg <sup>-1</sup> VS)
V	Volume (mL)
G	Experimental methane production (NmLCH <sub>4</sub> )
K <sub>G</sub>	Kinetic constant of methane production (Lg <sup>-1</sup> VS h <sup>-1</sup> );

## 1. Introduction

Morocco is facing a continuous increase in the volume of waste produced. This increase is due to the growth in the number of inhabitants, changes in production and consumption patterns and lifestyle improvement. In Morocco we generate annually more than 9 million tons of municipal solid waste [1]. Household organic waste fraction (HOWF) is about 65% which give almost 6 million tons per year. The composition of household organic waste fraction (HOWF) varies with seasons and consumption types, and has a negative impact on the environment and human health. The AD or Methanization is one of the suitable treatments for organic waste. it consists in the transformation of organic matter into biogas (approximately 60% methane, 40% CO<sub>2</sub>) and water by a complex microbial ecosystem operating in the absence of oxygen. It can be done under mesophilic or thermophilic conditions [2]. The process includes 4 steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis [3]. Hydrolysis and methanogenesis are considered as rate limiting steps depending on conditions like substrate types, temperature, pH and sludge retention time (SRT) etc... [4]. Some substrates such as lignocellulosic materials are resistant to AD and can influence the biodegradability. Hence, pretreatment of lignocellulosic matter to improve its physical accessibility to microbes and/or hydrolyse constituent compounds of it is mostly important regarding AD [5].

In order to increase biodegradability and biogas production, many treatments have been reported, including chemical, biological, thermal and mechanical pretreatment. Among different pretreatment methods, mainly the MP and UP pretreatment enhances the solubilization of substrate and promote the hydrolysis phase, biogas yield and biodegradability during AD [6,7]. All ultrasonic pretreatment studies found in the literature have been focused mainly on sewage sludge [8]. For organic household waste, most studies focus on physical pre-treatment, with a predominance of mechanical pre-treatment [9].

In descriptive terms, the reaction stage of methanogenesis is traditionally simplified and reduced to first-order kinetics with respect to substrate concentration, and according to Winkler (1983), the variation of the biodegradable substrate over time is a function of the specific kinetic constant of methane production and the concentration of biomass in the digester [10,11].

The main objective of this paper is to evaluate the AD efficiency and stability using HOWF under CMUP in CSTRs. We evaluated the combination treatment impact on the biodegradability and methane yield during the process under mesophilic conditions in semi-batch operation. The OFHW underwent previously a mechanical treatment (grinding), to reduce the particle size, homogenize the substrate and to facilitate the digester feeding, this experiment was considered as a control in order to compare the results and to evaluate the CMUP effect on the process.

## 2. Materials and methods

### 2.1. Experimental setup and raw material

The experimental setup used at laboratory scale consisted of 1L continuous stirred-tank reactor (CSTR). The reactor content was magnetically stirred, and temperature was maintained by a thermostatic jacket at 37 °C for mesophilic conditions. The experiment was carried out in semi-batch operation. The methane volume produced during the process was measured using a connected tank to the reactor. The reactors were inoculated with methanogenically active sludge obtained from a full-scale anaerobic reactor used to treat sewage sludge from an urban wastewater treatment plant.

The studied waste is a mixture of samples taken from a several households of various cities in Morocco, manually sorted out to extract the inorganic fraction. The household waste studied consists mainly of kitchen waste. It was

mixed and blended by a kitchen blender to insure a better homogenization, and diluted by distilled water. For this experiment, we required 1 kg of the raw material (HOWF).

## 2.2. Pretreatments

### Mechanical pretreatment (MP)

As MP used in this work, a kitchen blender Moulinex was used to reduce the size of the fibres and homogenize the HOWF. The MP experiment serves as a control.

### Combined Mechanical–Ultrasonic pretreatment (CMUP)

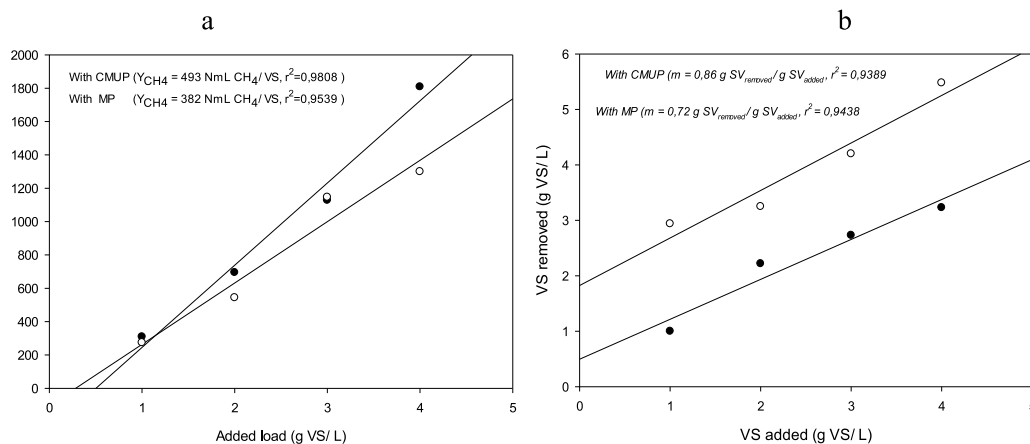
Ultrasonic pretreatment is one of the most recent techniques used to pretreat organic material, it is based on monolithic cavitation that creates a millions of microbubbles, carrying out a molecular disintegration and produce a high alteration in the chemical nature through the formation of free radicals.

The ultrasonic pretreatment during the experiment was conducted using a 9 L P-SELECTA ultrasonic equipment, for 24 min at a frequency of 40 kHz. The choice of conditions for ultrasound pre-treatment has been based mainly on the literature. Previous studies have shown that the performance of anaerobic digestion increases by increasing the duration of ultrasonication. Study conducted by Q. Wang, 1999 on mixed sludge (MS) in bath and mesophilic conditions, shows that sonication time of 30 min and 9 kHz increase  $\text{CH}_4$  production from 210 to 345  $\text{mLg}^{-1}\text{VS}$  compared to unsonicated (MS). Moreover, C.P. Chu, 2002 noticed that a sonicated activated sludge (AS) for 20 min and 20 kHz in batch conditions at 35 °C increase  $\text{CH}_4$  production by 104% compared to untreated (AS) [12].

## 3. Results and discussion

### 3.1. Methane yield and biodegradability

Methane production was measured throughout the process. As shown in Fig. 1(a), by fitting pairs of values of the maximum experimental volume of methane produced in each load ( $\text{NmLCH}_4\text{g}^{-1}\text{VS}$ ) to a straight line, the methane yield coefficient coincides with the slope of the regression line [13], which was found to be 493 and 382  $\text{NmLCH}_4\text{g}^{-1}\text{VS}$  respectively for the control and the CMUP experiment. The methane yield results obtained for the two experiments show that the application of CMUP on the substrate before digestion significantly improves methane production.



**Fig. 1.** (a) Comparative Methane yield with MP and CMUP experiments, (b) Comparative biodegradability with MP and CMUP experiments.

The biodegradability rate can be illustrated by plotting the removed VS as function of added VS substrate for each experiment, as shown in Fig. 1(b). The slope of the straight line indicates the percentage of biodegradability rate [14]. The biodegradability in the both experiments with MP(control) and CMUP is 72% and 86% respectively. By applying the CMUP, we noticed an improvement of biodegradability accompanied with an increase in methane production.

All studies conducted on the ultrasonic pre-treatment process on organic solid matter have shown an improvement in methane production and biodegradability. Chen et al. (2008), determine the effects of the ultrasonication process on the hydrolysis and acidogenesis phase of solid organic waste and found a 53% improvement in volatile solids degradation compared to untreated substrate, due to desorption of volatile acids from the surface of substrate particles and their direct interruption by ultrasound [15]. Study by Elbeshbishy et al. (2012), pointed out that the ultrasonication of food waste for a period of 30 min allowed a 16% increase in biogas production [16]. Similar results have also been obtained for the ultrasonication pretreatment of the mixture of the organic fraction of municipal solid waste and sewage sludge [17]. When compared to other pre-treatments (thermal, chemical, etc.), ultrasonication has proved to be the most polyvalent, as it has been effective with different types of solid substrates. Alessandra Cesaro et al. (2013), pointed out that ultrasonication was more competitive than ozonation as a pre-treatment technique for HOWF, as it increased the solubilization rate of organic matter by 9% [18].

In this study the CMUP for 24 min allowed respectively a 14% and 29% improvement in methane production and biodegradability. Applying a mechanical pretreatment before ultrasonication improves the biodegradability. The reason behind this increase is due to decrease in the particle size after mechanical pretreatment and improvement of organic matters solubility after ultrasonic [19]. Sonication generated intense microconvection in system that caused faster disintegration and solubilization of biosolid [20].

### 3.2. Kinetic study of methane production

In order to characterize this experiment kinetically, by non-linear regression, the first kinetic model was used to adjust the experimental data [14,21]. Fig. 2(a) shows the variation of the volume of accumulated methane ( $G$ ) as a function of time (h) for the both experiments. The variable concerned is the amount substrate (g VS) added to the reactors. The results show that a larger volume of methane was produced when the substrate load increased. In addition, the values of the specific kinetic constant  $K_G$  provide information on the kinetics of methane production. Fig. 2 (b) represents the  $K_G$  values as a function of the added loads, a slowing of the specific kinetic constant  $K_G$  from 0.20/h to 0.01/h, was observed with the increase in the added substrate concentration from 1 to 4 gVS $l^{-1}$  with MP and from 0.072/h to 0.01/h for CMUP, which indicates the existence of an inhibition phenomenon in the end of the process. Whereas the decrease slopes of  $K_G$  give an idea of the inhibition speed and its magnitude, as shown in Fig. 2(a), we notice that the control showed the most important inhibition with the highest  $K_G$  slope, the digestion of the HOWF after CMUP showed the lowest inhibition which explains the stability of the  $K_G$  during this experiment.

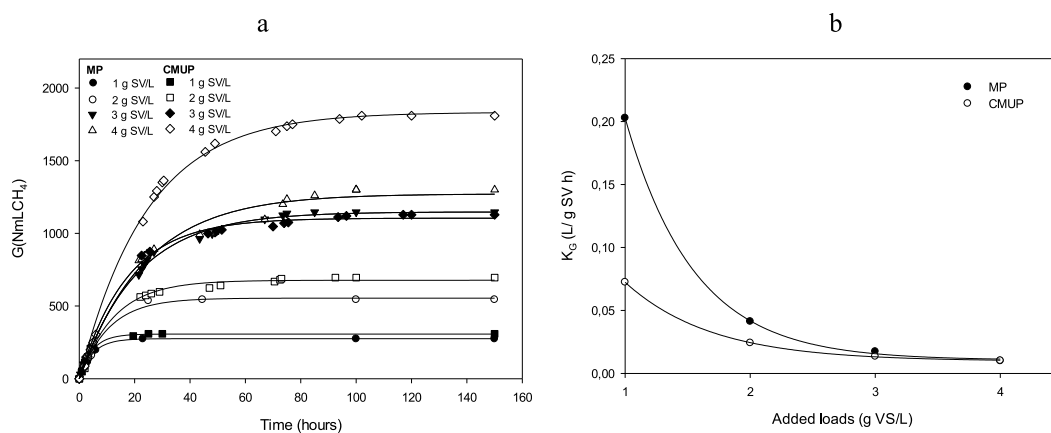


Fig. 2. (a) Methane production evolution with MP and CMUP, (b)  $K_G$  evolution with MP and CMUP.

## 4. Conclusion

The anaerobic digestion of HOWF with combined mechanical–ultrasonic pretreatment for 24 min was stable during the process, reaching a methane production yield of 496 ( $mLCH_4g^{-1}VS$ ). Ultrasonic pretreatment improves the substrate degradation and then methane production respectively by 14% and 29%.

From the research that has been conducted, we can conclude that the proposed combined pretreatments technique it was an effective way to improve the HOWF methane production and biodegradability. More experiments on combined mechanical–ultrasonic pretreatment effect, with new conditions, and with more parameters monitoring during the AD process, are still necessary to extend our knowledge.

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