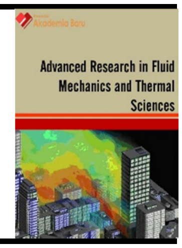
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Effects of Co-digestion of Camel Dung and Municipal Solid Wastes on Quality of Biogas, Methane and Biofertilizer Production

Open Access

Benaissa Nawel Kheira[1,2,*], Belkheir Dadamoussa[3,4], Abdelaziz Bendraoua[2,5], Maizirwan Mel[6], Brahim Labed[1]

[1] Laboratoire de Recherche Scientifique Sciences & Environnement (Bioressources, Géochimie-Physique, Législation et Développement Socio-Economique), Centre Universitaire Amine El Okkal El hadj Moussa Eg Akhamouk de Tamanghasset, Serssouf 11000 Tamanrasset, Algeria
[2] Département de Chimie Organique et Industrielle, Faculté de Chimie, Université des Sciences et de la Technologie d'Oran Mohamed Boudiaf, El Mnaouar, BP 1505, Bir El Djir 31000 Oran, Algeria
[3] University of Ghardaïa, BP 455, 47000 Ghardaïa, Algeria
[4] Laboratoire de Protection des Écosystèmes en Zones Arides et Semi-Arides, University Kasdi Merbah, 30000 Ouargla, Algeria
[5] Laboratoire de Synthèse Organique, Physico-chimie, Biomolécules et Environnement (LSPBE), USTO-MB, 31000 Oran, Algeria
[6] Department of Biotechnology Engineering, Faculty of Engineering, International Islamic University Malaysia (IIUM), Gombak, 50728 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 2 July 2016
Received in revised form 1 February 2017
Accepted 4 August 2017
Available online 29 November 2017

ABSTRACT

Biogas and biofertilizer production from anaerobic digestion of local organic solid waste in Algeria is an attractive choice for greener and cleaner environment. In this paper, the study focused on the effect of co-digestion of municipal solid organic wastes (MSW) and camel dung (CD) for the quality production of biogas (methane) and bio fertilizer products. The concentration of methane production is the preeminent aim of this work. The experiment was set by feedstocks preparation where organic waste was mixed with tap water at 1:1 ratio and it allowed to digest at temperature of 40 °C. The operating hydraulic retention time (HRT) was set at 35 days. Physicochemical properties of feedstocks and constituent elements of the digestate were determined by American Public Health Association methods. The experimental study indicated that underdefined operational conditions such as constant organic loading rate (OLR) of 0.6 kg per day, hydraulic retention time (HRT) of 35 days and temperature of 40C from MSW and MSW and CD mixtures of ratio at one to one resulted in a higher methane production (57.3%) compared to mono-digestion of camel dung that produced 45.6% of CH_4) in a pH range between 7.0 to 8.1. The improvement has also found related to high biodegradability of the MSW, the slight ammonium concentration, the optimization of the carbon-to-nitrogen ratio (C/N 25.8:1) and to the well-balanced nutrients content of the feedstock. The digestate coming from anaerobic co-digestion has also used as bio-fertilizer and this by-product has a benefit to avoid the harmful effect in the digester system and in the surrounding environment. It is shown clearly that the MSW and CD are highly desirable substrates for anaerobic co-digestion with regards to their good biodegradability, high methane yield and good bio-fertilizer quality

Keywords:
Biogas, methane, anaerobic co-digestion, municipal solid wastes, camel dung, bio-

[*] *Corresponding author.*
E-mail address: kheira.benaissa@univ-usto.dz (K. Benaissa)

fertilizer

1. Introduction

Energy is a crucial factor in Algerian's economy, the recent Algerian's had faced severe economy crisis as the oil incomes fall up to 70% in less than two years, which made the country lose half of its external receipts and causing an important deficit of its trade balance. The fossil fuel reserves will not last eternally (some 40 to 50 years) and the human activity causes a change of the climate, which has important repercussions. The need to find an alternative and renewable source of energy is becoming increasingly important for the sustainable development. According to the National Waste Agency (Agence Nationale des Déchets -AND), more than 28,219 tons of municipal solid wastes are generated per day or 10.3 million tons each year [1], which can lead to a serious problem in the future. Animal wastes present important resources of crop fields fertilizer and organic matters enhancement. Ruminants (camel, horse, cow, sheep and goat, etc. as domestic livestock, produce important amounts of methane as an element of their normal digestive processes [2]. Only few studies were found on methane produced by camel dung [3]. Thus, this study is one of the first studies on anaerobic co-digestion of municipal organic solid wastes and camel dung mixtures. Biogas and bio-fertilizer are the major products from anaerobic digestion, which contains important microbial biomass, partial-degraded organic matter and inorganic substances, and so can be used as soil fertilizer [4]. Fruit and vegetable wastes with high anaerobic degradation can be effectively decomposed for methane and compost production [5].

In Algeria, the first biodigester was constructed in 1939 under the impulse of two teachers of the National School of Agriculture of Algiers Ducellier *et al* [6]. That work has been considered as precursor of the biogas production mastery not only in Algeria but also at the world level. Based on their patent, many agricultural installations were equipped with gas digesters of manure, and that various pieces of equipment of valorization of biogas have been developed. Quickly, the activities in the field of bio-methanization decreased after the discovery of less expensive fuels at the end of the Forties in Algeria, and since, a slight interest was attributed to this biotechnology. So, the establishment of an effective cooperation on April 2015, between Sciences and Environment research laboratory at Tamanghasset Centre University and The Environment Directorate to build up the first biogas digester (Figure. 5) in the urban park of the city of Tamanrasset as an alternative energy test, was an important action for the energetic development of the south of Algeria. In fact, the bio-digester with a capacity of $15m^3$ is designed to produce biogas from fermentable municipal solid wastes (MSW) and camel dung (CD) as microbial inoculum bio-resources for enhanced biogas production and bio-economy approach. This biogas will be utilized to replace, or afford a combustible gas for cooking or heating.

In the purpose to launch the bio-digester of Tamanrasset city, it was needed to relay on good control of the process regarding the operating conditions of the region. Therefore, the present paper presents an evaluation of a laboratory scale experiment of biogas and bio-fertilizer production quality from three different substrates in batch reactors, under mesophilic temperature and similar conditions of pressure and stirring that allow the growth of microbial biomass.

2. Methodology

2.1 Feedstocks Preparation

Substrates sample were prepared from organic fraction of municipal solid wastes (MSW) (fruits and vegetables) and camel dung (CD) and waste mixture. Immediately after collection, substrates have been processed to reduce to small size (3–4 mm) using an electric hand blender. Tap water was used and added in this experiment with a ratio of 1:1 (w/v) as in Table 1. Substrates were evaluated before fed into the digesters (the digesters were not operated or before running the experiment). The tap water containing moderate quantity of calcium ions is most preferred for anaerobic digestion (AD) process while hard and deionized water having higher and very small calcium level are not suitable for optimum biogas production [7]. The total hardness is in the range of 100-200 mgL^{-1} for getting a higher yield in biogas and faster AD process. The total hardness of the tap water used in this experiment is 186.11 mgL^{-1}.

Table 1
Media composition in each reactor

Reactor	Volume of tap water, L	Mass of MSW, kg	Mass of CD, kg
R1	0.6	0.606	/
R2	0.606	/	0.602
R3	0.602	0.301	0.301

2.2 Experimental Method

A diagram of the experiment is illustrated in Figure 1. A working volume of 2 litres for each reactor (digester), which prepared using glass flasks fitted with airtight rubber seal. The batch reactors were set up with the aim to investigate on the methane production rates with the same conditions of pressure and temperature. The three reactors (R1, R2 and R3) are connected with polyvinyl chloride (PVC) tubing and filled with acidified water (about pH 3) [8]. The downward displacement water system was used to measure biogas produced through the indirect measurement of a liquid column height. The reactors were operated with a run time of 35 days.

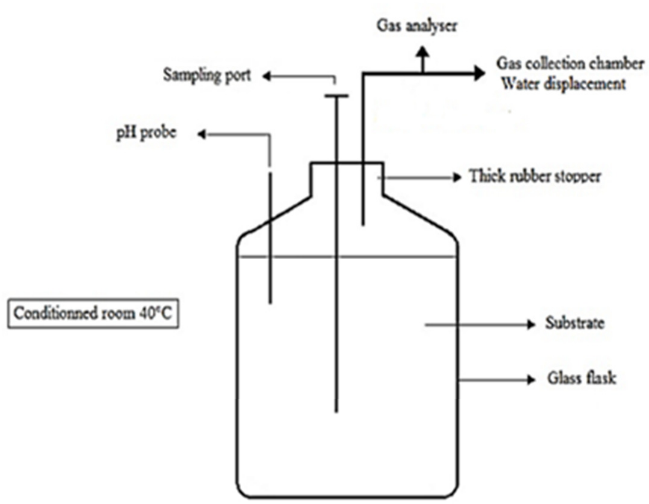


Fig. 1. Schematic diagram of each reactor

The substrates in the reactors containing MSW (R1), CD (R2) and MSW&CD (R3), the media composition in each reactor is shown in Table 1. Biogas production, pH of samples was measured daily 35 days. A numeric pH-meter (PHYWE, Germany) was used for pH measurements. The HACH DR1900 was used for chemical analyses and the CR2200 thermal reactor for chemical oxygen demand (COD) samples preparation. The concentration on of methane was determined by connecting the sample to a gas analyzer GA45 (Geotechnical Instruments, UK). The temperature of the experiment was controlled and fixed at 40 °C in a room provided with a thermostat. Manual agitating was set and started after the 7th day. The reactors were mixed according to methods described in Kaparaju *et al*. [9] and Lindmark *et al*. [10] by rotating the digester 360° at each sampling. The optimum temperature for anaerobic digestion is represented in Table 2.

Table 2
Optimum experimental conditions required for anaerobic digestion

Parameters	Optimum experimental conditions	References
Temperature	Mesophilic range (25-45 °C); optimum biogas production at 35 °C	[13]
	Thermophilic range (45-70 °C); optimum biogas production at 55 °C	
pH	6.5-8.2	[18]
Organic Loading rate (OLR) and nutrient concentration	Varies according to the substrate and inoculum	[18]

2.3 Sampling and analysis

The parameters were monitored during the fermentation daily and recorded as: (a) volume of gas produced (kg/fresh matter), (b) methane content (%), (c) the pH of digestate, and (d) chemical analysis of digestates after HRT completed. Physicochemical characteristics were monitored before and after fermentation according to standard procedures [11]. Chemical parameters were investigated include pH, nitrate, nitrite, total nitrogen, total phosphorus, total organic carbon, chemical oxygen demand and 5-day biochemical oxygen demand. The fermentation study was carried out at thermophilic condition as it has been reported by Gazifard *et al* [12]. The digestate was cured at controlled temperature at 40 °C. However, constituent elements of the digestates obtained were determined using standard methods after 90 days of incubation [11].

3. Results and Discussion

3.1 Substrate Characterization

A waste analysis is one of the most essential steps in the anaerobic digestion process, knowing that the general composition of the input material is very important to evaluate the biogas produced. The waste primary analyses are shown in Table 3 and Table 4. The MSW had dry matter (DM), organic matter (OM) and material matter (MM) content of 14%, 98.6% and 1.4% (dry basis), respectively. The camel dung had DM, OM and MM content of 39%, 26.1% and 73.9%, respectively and a pH of 5.9 (before mixing with tap water, respectively.

3.2 Process Factors of Digestion

The temperature was fixed at 40°C throughout the study. Anaerobic process is very sensible to temperature [13]; the change of acetic acid into methane depends mostly on temperature but conversion into acetic acid will not be affected by slight temperature variations [14]. Higher temperature affects the activity of hydrogenotropic methanogens in the anaerobic process and enriches hydrogen producing bacteria and spore forming bacteria. The pH, the Organic Loading Rate (OLR) and balancing nutrients in the feed are among the principal parameters, which act on the bio-methanization process. From the physicochemical characteristics of the feedstocks and the resultant digestates as shown in Table 5, the amount of COD, organic carbon, and nitrite content in the R2, R1 and R3 was found to be increased by 39%, 59.5%, 42.51%, 72.62%, 86.05%, 62.87 % and 6.51 %; 54.86 %, 45.33 %, respectively, nitrate content was reduced by 62.64%, 27.07% and 45.56%, respectively. Nitrogen was reduced in R2 by 44.04% and it however increased in R1 and R3 by 34.26% and 77.05%, respectively. BOD5d was reduced after anaerobic digestion in R1 and R3 by 42.12% and 33.89%, respectively, and it increased in R2 by 87.8%. Total phosphorus was reduced in R1 by 19.18% but it increased in R2 and R3 by 55.51% and 22.21% respectively when compared with the original feedstock. There were increases in total and volatile solids in the three reactors after the anaerobic digestion.

It is about 42.12% and 33.89% BOD5d reduction in the R1 and R3 digestates when compared to the feedstocks that could be traced using the biodegradation of the organic matter in the substrate due to the activities of mesophilic microorganisms. Another parameter, C/N ratio is also an essential parameter to enhance rapid and total organic matter decomposition.

3.3 Co-digestion Performance on Mesophilic Anaerobic Process

The three reactors were set-up under mesophilic conditions for a hydraulic retention time of 35 days with the given reference digesters (R1, R2) treating organic municipal solid wastes and camel dung, respectively, and the co-digestion digester (R3) treating equal parts of camel manure and organic fraction of fruits and vegetables. As presented in Figure 2, the pH is almost maintained around 7 until then end of fermentation. While, in Figure 3, the daily gas produced fluctuated and get better fermentation at days 20, it is about 7 kg/FM (for MSW-CD Mixed). In Figure 4, R1 show low proportion in methane production (CH_4 8.1%) when compared to with R2 (CH_4 45.6%) and R3 (CH_4 57.3%).

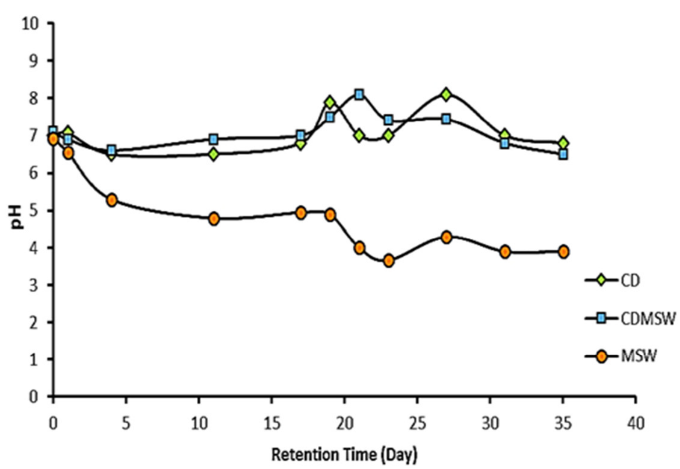


Fig. 2. pH development during digestion of CD, CDMSW and MSW

From then onwards the feedstocks and the digestates of the three digesters were characterized during 35 HRT and after 90 days of incubation. The pH of the reactors affects the anaerobic digestion process and efficiency of the digestion process [14]. Methanogens work effectively between pH range of 6.5–8.2 (see Table 2), with an optimum pH 7.0 [15, 16]. Fang *et al*. [17] finds that pH is wide-ranging in plants, so its optimal value varies relatively with feed and process technics.

Beccari *et al*. [18] specified that only 20-30% of polyphenols were decomposed in MSW in anaerobic methanogenic conditions. Moreover, Sorlini *et al*. [19] studied the effect of polyphenols in organic MSW on its own biodegradation and he has as a result that these elements are the responsible for anaerobic process inhibition. pH varies because of many factors: alkalinity of the system and by fraction of CO2 and hydrogen produced during the process, volatile fatty acids and bicarbonate concentrations in the feed [14]. Having control on the rapport of bicarbonate and volatile fatty acids in the media composition is the key to maintain constant pH value [20]. For controlling pH, NaHCO3 and NaOH must be added in the continuous reactor during start-up period [21].

Table 3
Characteristics of the MSW

Dry Matter (DM)	14%	Analytical Protocol Dry oven 60°C then 105°C	ISO11465	
pH	5.9	Water, mat. /solution 1/10	ISO10390	
Composition				Equivalent in kg/T of raw material
Organic Matter (OM)	Organic Matter (OM)			143
$N\text{-}NH_4$	Traces			0.1
oxydable carbon	43.5%	Walkley-Black.	ISO14235	
C/N ratio	7			
Mineral Matter (MM)	1.4%			2
P_2O_5	0.6%	Oven 550°C, HCl 4N		0.8
K_2O	2.5%	Oven 550°C, HCl 4N		3.6
MgO	0.2%	Oven 550°C, HCl 4N		0.4
CaO	2.6%	Oven 550°C, HCl 4N		3.7
Na_2O	0.5%	Oven 550°C, HCl 4N		0.7

The concentration of organic acids in these digestates was low, whereas the pH remained in the neutral status during the experiment period and could be as buffering agent of the camel dung, which is proportional to bicarbonate concentration. The observed increase in pH of R2 and R3 feedstocks could have contributed to the reduction in pathogens in the bio-fertilizer digestates, as most pathogens cannot tolerate in high pH levels. Yun *et al*. [15] have also reported that a large amount pathogen is destroyed by the metabolic heat generated by microorganisms during anaerobic digestion. Temperature was constant in mesophilic conditions (40 °C) throughout the period of the anaerobic digestion indicating that the bio-fertilizers can be produced within such temperature degree. A drop of pH was detected in R1; pH was 7.0, and decreased to 4.9, after that the pH decreased again to 3.5–3.9. Therefore, a lower biogas production was observed in this reactor (Figure 3). It should be noted that the biogas and methane yield from the CD digester were in the low range of what has been previously reported [22]. The low biodegradability of the camel dung at mesophilic conditions could be explained by:

(i) less organic matter was available for digestion (26.1%) (see Table 2) and (ii) the high concentration of Ntotal (5,718.8 mg/L) in the digester which might inhibit methanogens. However, the process stability was not affected by NH3 inhibition, but directed the anaerobic digestion to an "inhibited steady state" [25, 26]. The increase in the biogas produced from R3 (Figure 3) could be related to several factors: (i) the high biodegradability of MSW associated with CD, (ii) the slight concentration of the Ntotal (886.9 mg/L) (iii) the optimization of the C/N ratio. Specifically, the manure digester (R2) had a C/N ratio of 22.5:1 whereas (R3) had a C/N ratio of 25.8:1 calculated as COD/TN [24]. Since optimum range values for C/N ratio between 20:1 and 70:1, it is clear than that both R2 and R3 presented better conditions for the microorganisms involved in the anaerobic digestion process than R1 (C/N ratio 13.1:1). In contrast, due to the very low biogas produced (3.25 kg/fresh matter occurred on the 23rd day of incubation) in R1 which appeared to be affected by the solubilization of the organic matter. The characterisation of the mixture of MSW, which this mixture is similar than used in [27] (fraction of the organic matter (98.6%) and carbohydrates (43.5%)) (see Table 1). The significant biogas cumulated volume of the anaerobic co-digestion, about 7.2 kg/FM occurred during the first four days of the anaerobic digestion, indicated that the carbohydrates supplied by MSW had been transformed into biogas in R3. Therefore, it is suggested that microorganism's content in R1 and R2 had to hydrolyse more amounts of organic matter in the purpose to obtain nutrients, while in R3 sufficient easy substrate was available by mixing CD with MSW. However, some organic matter still presents in R2 and R3, which is indicated by volatile solid (VS) concentrations showed in Table 5. Thus, it is required to add a larger hydraulic retention time to allow good biodegradability of organic matter into biogas production.

Table 4
Characteristics of the Camel Dung

Dry Matter		39%	Analytical Protocol		
			Dry oven 60°C then 105°C	ISO11465	
pH		7.3	Water, mat. /solution 1/10	ISO10390	
Composition					Equivalent in kg/T of raw material
Organic Matter		26.1%			102
	$N\text{-}NH_4$	Traces			0.1
	oxydable carbon	9.0%	Walkley-Black.	ISO14235	
	C/N ratio	3.4			
Mineral Matter (MM)		1.4%			289
	P_2O_5	0.5%	Oven 550°C, HCl 4N		1.8
	K_2O	0.5%	Oven 550°C, HCl 4N		1.9
	MgO	7.1%	Oven 550°C, HCl 4N		27.8
	CaO	11.4%	Oven 550°C, HCl 4N		44.7
	Na_2O	0.2%	Oven 550°C, HCl 4N		0.6

3.4 Quality of Bio-fertilizer Production

Table 6 shows the properties of the bio-fertilizer obtained from the digestate after 90 days of incubation. From Table 6, TOC, TN and TP contents of the CD, MSW and CD&MSW digestates were found to be 44.2%; 27.2%; 58.5%, 2.01%; 2.14%; 2.34% and 2.28%; 4.29%; 3.8%, respectively. These results are similar obtained by Owamah et al. [28]. Biodegradable organic matter concentration in the feed has a profound influence in the nitrogen comportment because it can cause N-immobilization and O2 exhaustion that tend to an extreme in soil microbial activity. [29].

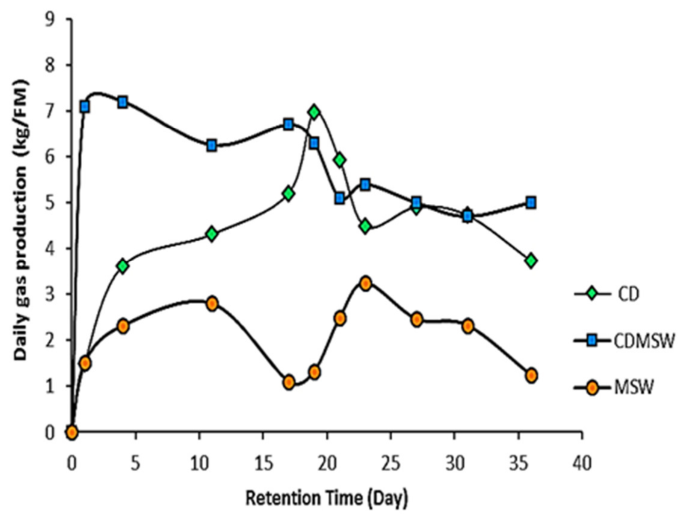


Fig. 3. Daily biogas production from the digestion of CD, CDMSW and MSW

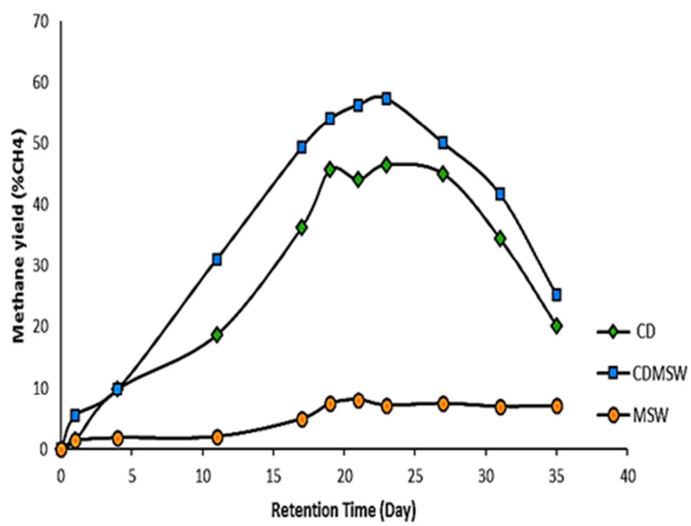


Fig. 4. Cumulative methane production from the digestion of CD, CDMSW and MSW

As shown in Table 5, it has the reduction of the BOD5d values in R1 and R3 about 42.12% and a 33.89%, respectively. As suggested by Ponsà *et al*. [30] amount of 2 mg O2 g^{-1} VS h^{-1} and 6 g O2 L^{-1} could be a safe agricultural use of digestate and this R1 and R3 byproduct could be qualified to be used as soil fertilizers because the BOD_{5d} within the range of 2.5 and 2.75 gL^{-1} respectively.

Table 5
Physicochemical parameters of the digesters feedstock before and after digestion (HRT 35 days)

Parameter	Before			After			% ±		
	R2	*R1*	*R3*	*R2*	*R1*	*R3*	*R2*	*R1*	*R3*
Total solids (%)	8.7	18.3	22.8	9.2	21.4	23.5	5.43 (+)	14.48 (+)	2.97 (+)
Volatile solids (%)	7.9	16.7	21.7	8.4	18.6	22.1	5.95 (+)	10.21 (+)	1.8 (+)
COD (mgl^{-1})	52,013	26,900	45,461	85,246	66425	79088	39 (+)	59.5 (+)	42.51 (+)
BOD_{5d} (mgl^{-1})	1,280	4,320	4,160	10,500	2,500	2,750	87.8 (+)	42.12 (-)	33.89 (-)
Nitrite (mgl^{-1})	20.6	7.8	11.1	22	17.3	20.4	6.51 (+)	54.86 (+)	45.33 (+)
Nitrate (mgl^{-1})	915.6	301.7	481.8	342	220	262.2	62.64 (-)	27.07 (-)	45.56 (-)
Total nitrogen (mgl^{-1})	5,718.8	2,265.2	886.9	3,200.2	3,446.1	3866	44.04 (-)	34.26 (+)	77.05 (+)
Total phosphorus (mgl^{-1})	145,9	175.3	223.1	328.1	1,41.7	286.8	55.51 (+)	19.18 (-)	22.21 (+)
Total organic carbon (mgl^{-1})	19,713	16,761.5	13,927	72,012.5	45,150	99870	72.62 (+)	86.05 (+)	62.87 (+)
pH	7.3	5.9	6.9	6.8	3.9	6.5	6.84 (-)	33.89 (-)	5.79 (-)
Odor	++	+++	++	-	+	-	/	/	/

Table 6
Elemental composition of the resulting bio-fertilizers (HRT 90 days)

Parameter	Proportion (%)		
	R1	R2	R3
pH	3.1	7.2	7.4
Total phosphorus (%)	4.29	2.28	3.8
Total nitrogen (%)	2.14	2.01	2.34
Potassium (%)	6.42	7.21	7.3
Total organic carbon (%)	27.2	44.2	58.5
Carbon / Nitrogen ratio	13:1	22:1	25:1

Even though, a longer HRT, a post-treatment and a final refining would be recommended in the purpose to avoid harmful effect on plant and on the environment. Heavy metals and minerals were not measured in this study.

4. Conclusion

In the present study it was proved that the association of MSW with CD resulted in a higher methane production (CH_4 57.3%) than mono-digestion of camel dung (CH_4 45.6%); improvement related to the high biodegradability of the MSW, the slight ammonium concentration, C/N ratio (25.8:1) and to the well-balanced nutrients content of this feedstock. The co-digestion process was set up through batch system and under low mixing conditions which represents an energy saving. Bio-fertilizer from the anaerobic digestate of R3 can be used to improve soil fertility. Even though, a longer HRT, a post-treatment and a final refining would be recommended to avoid harmful effect on digesters system and on the environment. Results from this study show significant reductions in BOD5d, nitrogen and organic carbon content in the digestates when compared to the feedstocks. It is suitable to note that the anaerobic co-digestion of kitchen waste with camel manure was demonstrated to be an attractive solution for the protection of the environment also for the economy of the energy for saharian rural regions. It is clear that with applying better equipment and adjustment of conditions and operating parameters for process optimization by numerical simulation, more reasonable results could be obtained.

Acknowledgement
A great thank to Mr. Ali Djacem and Mr. Mahi Tabet Aoul for their critical reading and correction of the English manuscript.

References
[1] Djemaci, Brahim, and Malika AHMED ZAÏD-CHERTOUK. *La gestion intégrée des déchets solides en Algérie. Contraintes et limites de sa mise en oeuvre*. No. 1104. CIRIEC-Université de Liège, 2011.
[2] Chhabra, Abha, K. R. Manjunath, Sushma Panigrahy, and J. S. Parihar. "Spatial pattern of methane emissions from Indian livestock." *Current Science* (2009): 683-689.
[3] Ngulde, Y. M., Yerima and B. M. Muhammad. "Determination of yield potential of cow and camel dung for the production of biogas in Maiduguri, North Eastern Nigeria." *Yobe Journal of Environment and Development* 4, no. 1 (2012): 59-71.
[4] Alburquerque, José Antonio, Carlos de la Fuente, Alicia Ferrer-Costa, Lucía Carrasco, Juan Cegarra, Manuel Abad, and María Pilar Bernal. "Assessment of the fertiliser potential of digestates from farm and agroindustrial residues." *Biomass and bioenergy* 40 (2012): 181-189.
[5] Mel, Maizirwan, Sany Izan Ihsan, and Roy Hendroko Setyobudi. "Process improvement of biogas production from anaerobic co-digestion of cow dung and corn husk." *Procedia Chemistry* 14 (2015): 91-100.
[6] Marcel, Albert Isman, and Rene Ducellier Gilbert Leon. "System for producing a pulsating circulation in apparatus containing gas evolving products." U.S. Patent 2,174,203, issued September 26, 1939.
[7] Lawal, ULI Yusuf. "EFFECT OF HARD WATER ON BIOGAS PRODUCTION PROCESS." (2016).
[8] Fountoulakis, M. S., S. Drakopoulou, S. Terzakis, E. Georgaki, and T. Manios. "Potential for methane production from typical Mediterranean agro-industrial by-products." *Biomass and bioenergy* 32, no. 2 (2008): 155-161.
[9] Kaparaju, Prasad, Inmaculada Buendia, Lars Ellegaard, and Irini Angelidakia. "Effects of mixing on methane production during thermophilic anaerobic digestion of manure: lab-scale and pilot-scale studies." *Bioresource technology* 99, no. 11 (2008): 4919-4928.
[10] Lindmark, Johan, Per Eriksson, and Eva Thorin. "The effects of different mixing intensities during anaerobic digestion of the organic fraction of municipal solid waste." *Waste management*34, no. 8 (2014): 1391-1397.
[11] Gilcreas, F. W. "Standard methods for the examination of water and waste water." *American Journal of Public Health and the Nations Health* 56, no. 3 (1966): 387-388.

[12] Ghazifard, Akbar, Rouha Kasra-Kermanshahi, and Zahra Etemadi Far. "Identification of thermophilic and mesophilic bacteria and fungi in Esfahan (Iran) municipal solid waste compost." *Waste management & research* 19, no. 3 (2001): 257-261.
[13] Mata-Alvarez, Joan, ed. *Biomethanization of the organic fraction of municipal solid wastes*. IWA publishing, 2002.
[14] Kondusamy, Dhamodharan, and Ajay S. Kalamdhad. "Pre-treatment and anaerobic digestion of food waste for high rate methane production–A review." *Journal of Environmental Chemical Engineering* 2, no. 3 (2014): 1821-1830.
[15] Eastman, John A., and John F. Ferguson. "Solubilization of particulate organic carbon during the acid phase of anaerobic digestion." *Journal (Water Pollution Control Federation)*(1981): 352-366.
[16] Sosnowski, P., A. Wieczorek, and S. Ledakowicz. "Anaerobic co-digestion of sewage sludge and organic fraction of municipal solid wastes." *Advances in Environmental Research*7, no. 3 (2003): 609-616.
[17] Liu, Cun-fang, Xing-zhong Yuan, Guang-ming Zeng, Wen-wei Li, and Jing Li. "Prediction of methane yield at optimum pH for anaerobic digestion of organic fraction of municipal solid waste." *Bioresource Technology* 99, no. 4 (2008): 882-888.
[18] Beccari, M., M. Majone, and L. Torrisi. "Two-reactor system with partial phase separation for anaerobic treatment of olive oil mill effluents." *Water science and technology* 38, no. 4-5 (1998): 53-60.
[19] Sorlini, C., V. Andreoni, A. Ferrari, and G. Ranalli. "The influence of some phenolic acids present in oil mill waters on microbic groups for the methanogenesis." In *Proceedings of International Symposium on Olive by Products Valorizatiomn, Sevilla, Spain*, pp. 81-88. 1986.
[20] Zhang, Lei, Yong-Woo Lee, and Deokjin Jahng. "Anaerobic co-digestion of food waste and piggery wastewater: focusing on the role of trace elements." *Bioresource technology* 102, no. 8 (2011): 5048-5059.
[21] Goel, R., T. Tokutomi, and H. Yasui. "Anaerobic digestion of excess activated sludge with ozone pretreatment." *Water science and technology* 47, no. 12 (2003): 207-214.
[22] Mandal, Tanusri, and N. K. Mandal. "Comparative study of biogas production from different waste materials." *Energy conversion and management* 38, no. 7 (1997): 679-683.
[23] Hansen, Kaare Hvid, Irini Angelidaki, and Birgitte KiÆr Ahring. "Improving thermophilic anaerobic digestion of swine manure." *Water Research* 33, no. 8 (1999): 1805-1810.
[24] Álvarez, J. A., L. Otero, and J. M. Lema. "A methodology for optimising feed composition for anaerobic co-digestion of agro-industrial wastes." *Bioresource technology* 101, no. 4 (2010): 1153-1158.
[25] Mata-Alvarez, Joan, Joan Dosta, Sandra Macé, and Sergi Astals. "Codigestion of solid wastes: a review of its uses and perspectives including modeling." *Critical Reviews in Biotechnology* 31, no. 2 (2011): 99-111.
26] Md Mizanur, Rahman, Mohd Faizal Hasan , Aminuddin Saat, Mazlan Abdul Wahid. "Economics of biogas plants and solar home systems: For household energy applications. " *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 33, no. 1 (2017): 14-26.
[27] Mata-Alvarez, Joan, S. Mace, and P. Llabres. "Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives." *Bioresource technology* 74, no. 1 (2000): 3-16.
[28] Owamah, H. I., S. O. Dahunsi, U. S. Oranusi, and M. I. Alfa. "Fertilizer and sanitary quality of digestate biofertilizer from the co-digestion of food waste and human excreta." *Waste management* 34, no. 4 (2014): 747-752.
[29] Alburquerque, José Antonio, Carlos de la Fuente, Alicia Ferrer-Costa, Lucía Carrasco, Juan Cegarra, Manuel Abad, and María Pilar Bernal. "Assessment of the fertiliser potential of digestates from farm and agroindustrial residues." *Biomass and bioenergy* 40 (2012): 181-189.
[30] Ponsá, Sergio, Teresa Gea, Llorenç Alerm, Javier Cerezo, and Antoni Sánchez. "Comparison of aerobic and anaerobic stability indices through a MSW biological treatment process." *Waste management* 28, no. 12 (2008): 2735-2742.