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Research Article

BIOGAS AND CH_4 QUALITY AND PRODUCTIVITY BY CO-DIGESTING DROMEDARY DUNG WITH KITCHEN WASTE AND SEWAGE SLUDGE WATER UNDER MESOPHILIC CONDITIONS

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ABSTRACT

Five laboratory-scale studies were set-up to investigate the effects of dromedary dung (DD) co-digestion with kitchen waste (KW) and sewage sludge water (SSW) at five ratios, under mesophilic conditions (31-35°C) by examining operation stability, CH_4 and biogas production potentials. The result obtained showed that KWDDSSW produced the highest CH_4 content (64.51%), followed by DDSSW (51.37%) and DDKW (34.77%). The daily CH_4 production was linearly correlated with pH, high volatile solids and COD degradation in the feedstock, indicating methane production was probably associated with higher supply of organic carbon source that favored the growth of active biomass. KWDDSSW and DDSSW were favored in terms of volume of flammable gas production of biogas and flamed on the 8th day. This study is being the first attempt on CH_4 production of combined wastes with DD of Algeria.

Keywords: Anaerobic co-digestion; biogas; methane; mesophilic conditions; kitchen waste; dromedary dung; sewage sludge water.

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1. INTRODUCTION

Algeria is experiencing a pressing need for municipal solid wastes management. A certain uncertainty affects the knowledge of the layer of waste in Algeria. The estimates made by the national agency of waste show that more than 11 million of tons of waste are produced a year on 2014 [1], and this production knows a significant progression [2]. With the appearance of new spending patterns of the populations, Algerian cities must cope with the phenomenon of an abrupt increase in the quantities of waste produced. A degradation of the environment and a risk on the public health are resulted from it. The main components of waste produced are: kitchen residues (organic) with an average rate of 54.4%, plastic 16.88%, paper 9.75%, glass 1.16%, metals 2.84% and others 14.97% [1]. The absence of the good management of waste could cause serious problems in the future. Algerian economy is heavily dependent on fossil fuels export, so the recent crisis is due to, the fall of oil incomes of 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 significant change of the climate, which has actually important repercussions. The need to find an alternative and renewable source of energy is becoming increasingly important for the sustainable development.

Methane is about 21 times more potent than CO_2 [3]. Combustion of biogas converts methane into CO_2 and reduces the GHG impact by over 20 times. By extracting methane out of waste will avoid its degradation in an open environment therefore reducing direct methane atmospheric emissions. Moreover, the energy provided by the biogas is, in the long run, likely to replace fossil fuel, which is the main contributor to GHG emissions. Energetic valorization of municipal organic solid waste (MSW) can be an alternative solution for sustainable development of Algeria, while at the same time a way for minimizing the global warming impact resulting from methane emissions in landfills and the fossil fuel consumption reduction. Flammable gas, which helps in satisfying the needs in gas for cooking and heating of rural areas such as the city of Tamanrasset, reducing forestation and desert encroachment, is produced through the conversion of this organic matter such as animal and green wastes into biogas.

The present study describes a laboratory scale experimental evaluation of the biogas production from five different mixing in batch reactors, in mesophilic temperature range of 31° to 35°C conditions for a retention period of 30 days, without continuous stirring allowing for microbial biomass growth [4] [5]. It is then important to define the ultimate biogas potential and methane production for several solid substrates, at the same time digested sludge that can be used as fertilizer for agricultural applications. This study is being the first attempt on biogas production from combined wastes with dromedary dung of Tamanrasset region (southern Algeria).

2. MATERIALS AND METHODS

2.1 Feedstock

Dromedary dung (DD) used as feedstock in this study, was obtained from Toudji camel farm in Tamanrasset (southern Algeria). The sewage sludge water (SSW) was collected from the Office National d'Assainissement (ONA) of the Tamanrasset city and the kitchen waste (KW) (fruits and vegetables) was obtained from the restaurant of the Tamanghasset University Center. KW was prepared as a mixture of 40% fruit, 25% potatoes and 35% vegetables. After collection, DD, KW and SSW were stored at 4°C until their utilization. Substrates were made up from the digestion of the organic fraction of KW, DD and SSW and the co-digestion under mesophilic conditions of different mixing wastes: R1 (DD), R2 (KW-DD), R3 (SSW-DD), R4 (SSW-KW-DD) and R5 (SSW-KW). Each mixture was chopped with an electrical mixer (approximately size 4.0 mm). The contents of each digester are shown in the Table 1. The digesters were not in operation before the fermentation experiment. The characteristics of the feedstocks are summarized in Table 3.

2.2 Tap water used in the experiment

According to Uli (2017), tap water containing moderate quantity of calcium ions is most preferred for favorable AD process while hard and deionized water having higher and very small calcium level are not as suitable for optimum biogas production. Therefore, some level of calcium is required to improve the yield in biogas production. Total hardness ranges from 100-200 mgL-1, which is in-line with [6].

Table 1. Contents of digesters

Reactor	Composition			
	SSW	KW	DD	Tap water
R1	/	/	2 Kg	2 L
R2	/	1 Kg	1 Kg	2 L
R3	2 L	/	2 Kg	/
R4	2 L	1 Kg	1 Kg	/
R5	2 L	2 Kg	/	/

2.3 Materials/Instruments

The materials/Instruments used for the research purpose are as follows: weighing balance (Sartorius), digital thermometer (PHYWE) (range 0° to 100° C), oven (Wisd), graduated transparent glass gas collectors, pocket colorimeter TM II (Hach) was used for chlorine measurements, WTW Oxitop® used for BOD measurements, SX736 portable multiparameter was used for physicochemical analysis (pH, conductivity and dissolved oxygen), Hach DR1900 spectrophotometer for chemical analysis, CR2200 thermal reactor. The proportion of methane was determined by connecting a gas analyzer GA45 (Geotechnical Instruments). The temperature of the experiment was controlled and fixed at the range of 31 to 35° C in a room provided with a thermostat.

2.4 Analytical methods

The following parameters of KW, DD and SSW were analyzed: pH, Conductivity, Dissolved Oxygen (DO) and Temperature (T°). The measurement devices were: Glass electrodes (SX736 portable multiparameter) to monitor the pH, the conductivity, the dissolved oxygen and the temperature of the samples [7].

Total Solids (TS) and Volatile Solids (VS) were determined following the guidelines given by standard methods 2540G and 2504D, respectively [7].

The 5-days Biochemical Oxygen demand ($BOD_{5\text{-days}}$) was determined by using a manometric device (WTW, Oxitop®) and following the standard methods 5210D procedure [7].

Chemical Oxygen Demand (COD), Total Nitrogen (N_{total}) and Total Phosphorus (P_{total})

analysis were measured by means of a spectrophotometer (DR1900, Hach® UK) following the LCK Cuvette Test System.

Total ($Cl_{2\ total}$) and free ($Cl_{2\ free}$) Chlorine were analyzed by using a pocket colorimeter TM II (Hach® UK).

Total hardness of tap water was determined by EDTA titration method described in [6] and following the standard methods [7]. This procedure was carried out two to three more times for the tap water samples in order to obtain at least two concordant titre values. All the tests were conducted in triplicate and mean values were reported.

Methane proportion was measured by using the GA45 gas analyzer (Geotechnical Instruments). In checking the flammability of the gas, a valve gas was used.

2.5 Experimental procedure

A schematic diagram of lab-scale experiment is shown in Fig 1. Five digesters with a working volume of 5L were constructed using plastic flasks hermetically sealed containing an influent/effluent port to allow sampling (see figure 1). The exact volume of each bottle was defined by weighing the water contained in the bottle. The batch digestion flasks were set up as a Bio-Methane Potential (BMP) experiment, with the aim to study the substrate's potential for biogas production with the same conditions of pressure (i.e. 1 atm) and temperature, which was set up in the range of 31 to 35°C. The temperatures were regulary monitored and recorded daily during the experiment period. The flasks were connected to PVC tubes filled with water acidified to pH 3 [8]. Biogas collected was measured by downward displacement of water at atmospheric pressure using calibrated 4 litres cylindrical jar for each reactor. The reactors were operated with a hydraulic retention time of 30 days and were set up and operated by the method described in [8], with slight modifications. The feed in the reactors was as follows; DD:tap water (R1) (1:1), DD:KW:tap water (R2) (1:1:2), DD:SSW (R3) (1:1), DD:KW:SSW (R4) (1:1:2) and KW:SSW (R5) (1:1), the media composition in each reactor is shown in Table 1. Biogas production, T°, pH, conductivity and Dissolved Oxygen of samples were measured once a day throughout the 30 days' experiment. BOD_{5-days}, COD, N_{total}, P_{total}, Cl_{2total}, Cl_{2free} were measured every five days of the experiment. Agitating was started after 7 days of incubation to allow the digestion process to start under similar conditions, increasing microbial biomass growth [4] and reducing initial instabilities that can be associated with high loading of the digester and leading to process failure [9]. The batch digesters were mixed in-line with [9] [10], minimally intermittently mixed by turning the flask 180° and backing up again at each sampling. The optimum temperature and pH for anaerobic digestion are presented in Table 2. In checking the flammability of the gas, a valve gas was used.

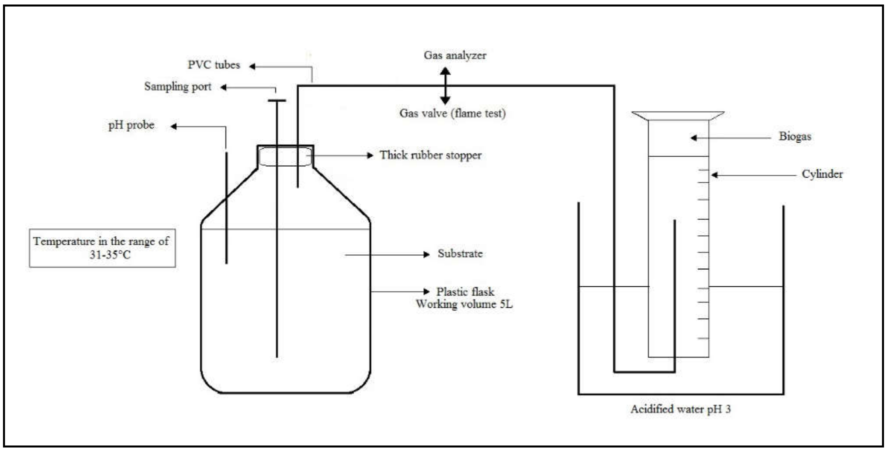

Fig.1. Schematic diagram of Lab-scale experiment

Table 2. Optimum conditions required for anaerobic metabolic activity

Parameters	Optimum conditions	References
Temperature	Mesophilic range (25-45° C); optimum biogas production at 35° C Thermophilic range (45-70° C); optimum biogas production at 55° C	[11]
pH	6.5 – 8.2	[12] [13] [14]
Organic Loading Rate (OLR) and nutrient concentration	Varies according to the substrate and inoculum	[15]

3. RESULTS AND DISCUSSION

3.1 Substrate characteristics

Five single-stage lab-batch reactors were tested during a period of 30 days to assess the co-digestion effects of kitchen waste (KW), the dromedary dung (DD) and the sewage sludge water (SSW) from methane production at mesophilic temperature (31-35°C). Characteristics of R1-R5 are summarized in table 3.

During the digestion process, the BOD5d decreased in R1-R5 34.21%, 57.93%, 79.26%, 81.69% and 42.12%, respectively. The average TP increased in R1, R2 and R4 while decreased in R3 and R5 (see table 3). The average Total Nitrogen, Total and Free Chlorine in addition to the conductivity increased in the whole digesters and the DO concentration slightly increased in R1-R5, but both the average influent DO for R1-R5 (0.1, 0.16, 0, 0 and 0.24 mg/L) and the effluent (0.8, 0.78, 0.36, 0.4 and 0.8 mg/L) DO concentrations, respectively, were anaerobic

Table 3. Physicochemical parameters of the digesters feedstock before and after digestion

Parameter	Before					After				
	R1	*R2*	*R3*	*R4*	*R5*	*R1*	*R2*	*R3*	*R4*	*R5*
Total Solids (%)	15.85	14.3	17.4	18.91	11.6	10.18	8.78	7.56	7.33	9.11
Volatile Solids (% TS)	80.3	79.18	86.5	89.71	63.3	51.3	42.33	36.1	34.64	52.45
$VS_{removal}$ (%)	/	/	/	/	/	36.11	46.53	58.26	61.38	17.14
pH	7.2	6.4	7.4	6.2	6.1	6.8	7.3	7.4	6.8	5
Conductivity (mS/cm)	17.71	26.3	20.7	27.1	20.1	38.4	39.1	30	41.1	25.5
DO (mgl^{-1})	0.1	0.16	0	0	0.24	0.8	0.78	0.36	0.4	0.8
COD (gl^{-1})	9.113	8.743	15.361	13.577	11.732	15.436	5.019	7.498	5.454	55.425
BOD_{5d} (gl^{-1})	2.280	4.160	2.580	5.120	4.320	1.500	1.750	0.535	0.937	2.500
$BOD_{5d\ removal}$	/	/	/	/	/	34.21%	57.93%	79.26%	81.69%	42.12%
Total Nitrogen (gl^{-1})	1.517	0.886	2.402	1.93	2.265	3.510	2.78	2.92	3.037	3.846
Total Phosphorus (mgl^{-1})	136.85	203.17	116.12	158.21	164.37	337.09	286.98	113.43	212.51	151.27
Total Chlorine (mgl^{-1})	99.2	144	134.4	137.6	59.2	440	440	205	370	245
Free Chlorine (mgl^{-1})	99.2	145.6	124.8	113.6	57.6	440	440	205	370	240
COT (g/L)	4.112	3.927	1.702	3.645	3.761	72.012	72.750	76.137	83.637	24.150
C/N ratio	2.71	4.43	0.708	1.888	1.66	20.51	26.16	26.07	27.54	6.28
Odor	++	+++	++++	+++	+++++	+	++	+	+	+++

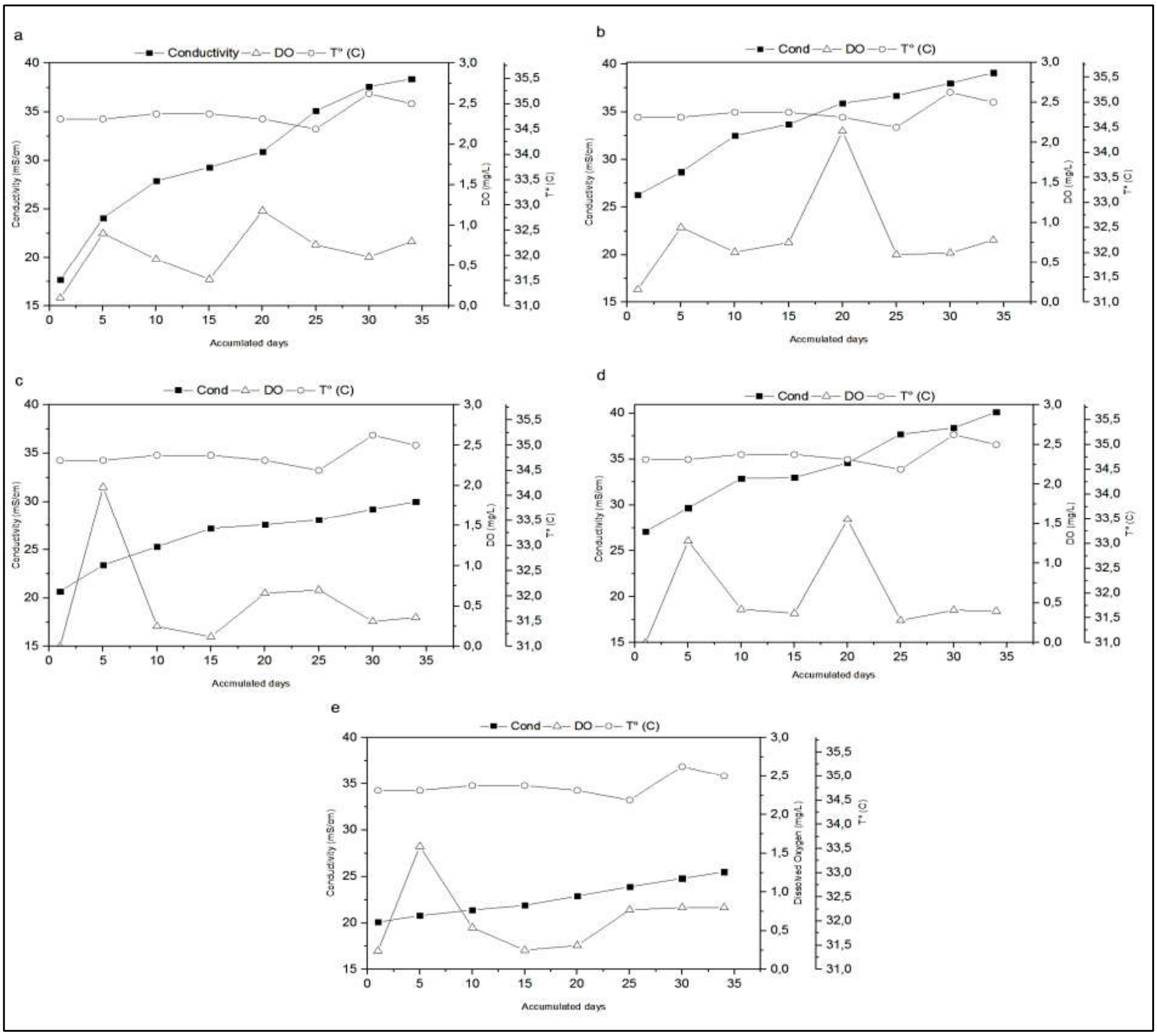

Fig.2. Physicochemical parameters influence during anaerobic digestion process on (a) R1, (b) R2, (c) R3, (d) R4 and (e)

3.2 Methane production process

- **Anaerobic production of dromedary dung**

Figure 3a illustrates the monitoring profiles of biogas, methane, pH and COD in the reactor fed with dromedary dung. The pH was approximately stable between 7.2 and 6.8. Low concentration of VFA at the end of pre-stage suggested that strict separation of acidogenesis and methanogenesis could not be maintained at this point and it would be better to shift the reactor to a new stage. In this regard, in R1, pH adjustment by 1 M NaOH was performed after pre-stage at day 5. Since, it was also observed that COD concentration in the reactor increased momentarily after the 7th day of incubation, but soon decreased again to previous COD concentration levels. This observation indicated that COD in the feed was approximately digested in the reactor. A cumulative of 42.35 Litres of biogas was produced at the end of the 30 days retention time-period from this reactor. Dromedary dung gas production started at the 1st day of incubation. The maximum of biogas and methane produced was on the 17th day with an amount of 1.86L and the 21st day with a proportion of 57.1%, respectively, and an average of 1.41L/d and 34.77%, respectively, during the retention time of experiment. There was no observed negative effect on reactor performance.

- **Anaerobic co-digestion of dromedary dung with kitchen wastes**

The characteristics of the reactor during the period of operation are shown in Fig. 3b. During the process, the pH in the reactor is approximately stable with values ranging between 6.4 and 7.3. Start-up was conducted with pH adjustment by 1 M NaOH at the day 5 of incubation. The VS mean proportion in the reactor was 61.33%, resulting in 50.1% VS average removal efficiency, which is close to the results recorded in previous study, referring to VS removal efficiencies between 50 and 86% in anaerobic digestion process [16]. A cumulative of 53.12 Litres of biogas was produced at the end of the 30 days retention time-period from this reactor. Dromedary dung with kitchen wastes gas production started at the 1st day of incubation. The digester produced as mean value of biogas and methane of 2.5L at the 14th day and 61% at the 20th day of incubation with an average about 1.77 L/d and 42.34%, respectively, throughout the experiment period. There were no previous studies on mono digestion of dromedary dung or its co-digestion with kitchen wastes but higher methane gas production was achieved in R2 than R1 (34.77%), which investigates on the mono-digestion of DD. This result may be explained by the well-balanced nutrients in the feedstock and high degradation of the organic matter. This observation indicated that COD in the feedstock was completely converted to methane. No negative effect was observed on reactor performance throughout the experimental period. The C:N ratio of this reactor was found adequate (26.16) because it is often suggested that C:N ratio in the substrate should be in between 20:1 to 30:1.

- **Anaerobic co-digestion of dromedary dung with sewage sludge water**

The performances of the system are shown in Fig. 3c. The pH value in the reactor was adjusted to 6.5 by 1M NaOH at day 5, and the recorded measurements were between 6.1 and 7.4. COD concentration in the reactor was found to be increased from the 1st to the 20th day of incubation to be decreased again after getting the lowest COD concentration levels. That was observed that the COD in the feed was completely digested in the reactor. R3 had 86.5% of VS, while this high proportion to TS (17.4%) depicts that large fraction of the DD and SSW was biodegradable and could serve as an important feedstock for biogas production. The C:N ratio of R3 was found adequate (26.07) because it is often suggested that C/N ratio in the substrate should be in between 20:1 to 30:1. A cumulative of 71.57 Litres of biogas was produced at the end of the 30 days retention time period from this reactor. Dromedary dung with sewage sludge water gas production started at the 1st day of incubation. Mean biogas volume during the operation was 2.82 L at the 11st day of incubation. Maximum of methane 66.4% produced on the day 21 of incubation period. The mean daily biogas production in the reactor was 2.38 L/d and the average of methane produced was about 51.37%. the considerably higher methane yield found in this work was likely due to the fact that the feed contained sewage sludge wastewater, previously found by others [17] to generate methane by digestion of fatty acids. However, to our knowledge no methane yield has previously been reported for DD digestion in mixed cultures. This reactor was secondly favored in terms of volume and quality of flammable gas produced.

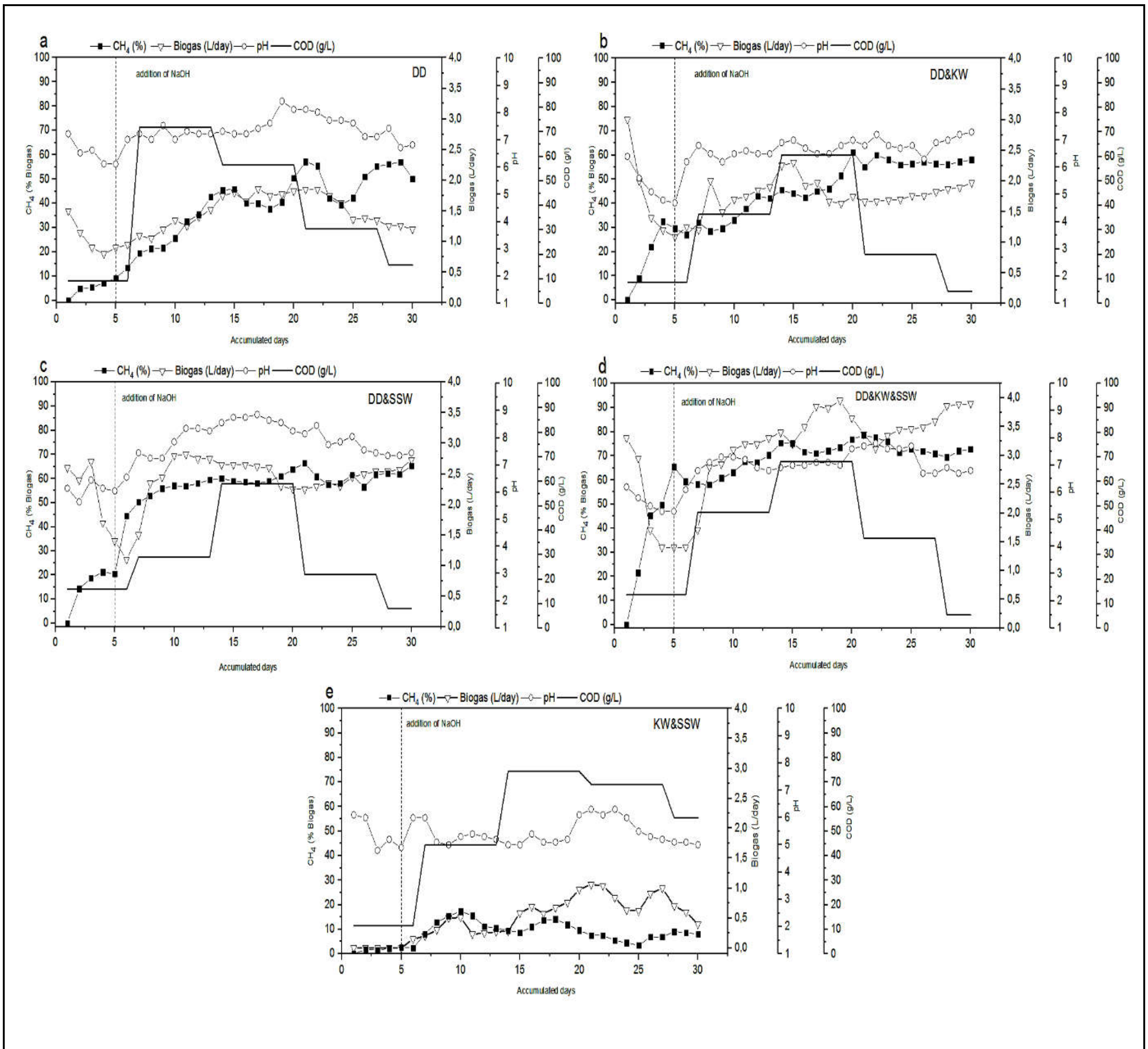

Fig.3. Profile of biogas, methane production, pH and COD during anaerobic digestion process of (a) R1, (b) R2, (c) R3, (d) R4 and (e)

- **Anaerobic co-digestion of dromedary dung and kitchen wastes with sewage sludge water**

The average biogas and methane production was 3.1L/d and 64.51%, respectively. Mean biogas volume and methane proportion during the experiment period was 3.95L on the 19th day and 78% on the 21st day of incubation, respectively. pH fluctuated during process from 6.2 to 6.8, resulting in insignificant fluctuations in the methane produced (Fig. 3d) thanks to the adjustment of pH to 6.1 in the start-up stage of the experiment. Variations in pH affected the fermentation process because the hydrogen ion concentration has direct influence on microbial growth [5]. [12], [13] and [14] found the optimum pH range for methane production to be 6.5-8.2 (Table 2), which is suitable for anaerobic microorganisms. This is an indication of high presence of organic pollutants in the feedstock. More is the volatile solids present more the production of biogas [18]. Furthermore, COD and VS concentration was 13.577 g/L; 89.71% before and 5.454 g/L; 34.64% after co-digestion process. This high proportion of VS to TS (18.91%) depicts that a large fraction of DD, SSW and KW was biodegradable and could serve as a very important feedstock for biogas and methane production. The C/N ratio of R4 was found very satisfactory (27.54) because, as mentioned before in this study, it is often suggested that the C/N ratio in the substrate should be in the range of 20:1-30:1. A cumulative of 93.15 Litres of biogas was produced at the end of the 30 days retention time-period from this reactor. Dromedary dung, kitchen wastes and sewage sludge water gas production started at the 1st day of incubation. The significantly higher methane produced from R4 (64.51%) observed in the experiment rather than R2 and R3 mixtures may be correlated with the biomass in the reactors. However, to our knowledge no methane volume has previously been reported for dromedary dung digestion in mixed cultures. The R4 process had a significantly greater biomass yield than the R2 and R3 process, due to the higher COD and VS concentration in the feed. Therefore, the supply of a higher organic carbon source favored the growth of active biomass in the reactor fed with DD:KW:SSW. This digester was the main favored in terms of volume and quality of flammable gas produced.

- **Anaerobic co-digestion of kitchen wastes with sewage sludge water**

Fig. 3e shows biogas volume and methane proportion of R5 throughout the run-up period. During start-up, biogas production was low and methane content increased slowly to 1.06 L on the 21st day and 17.3% on the 10th day in the reactor, respectively. This showed that acidification was strong over hydrolysis. The system was successfully started-up after pH adjustment on the 5th of incubation which dropped again rapidly, a possible explanation may be due to the high presence of fatty acids produced in the feedstock. A cumulative of 14.76 Litres of biogas was produced at the end of the 30 days retention time-period from this reactor. Sewage sludge water with kitchen wastes gas production started at the 6th day of incubation. The daily biogas production in the reactor was insignificant, which reaches 0.49 L/d and the average of methane produced was about 8.24%. The slight methane volume produced from this reactor was likely due to the fact that the feed contained SSW, previously found by others [17] to generate methane by digestion of fatty acids. pH fluctuated during process from 6.1 to 5.0, resulting in significant fluctuations in the biogas and methane produced. The pH value dropped below 5.0, lower methane production in R1-R4 was higher than R5. The possible explanation was due to the negligible biomass and unbalanced nutrients content in this reactor. The average methane content in biogas reduced linearly with decreased pH conditions [19]. COD and VS concentration in the reactor was 11.732 g/L; 63.3% before and 55.425g/L; 42.45% after the experiment retention time, respectively. This showed that the organic matter in the feed increased in the reactor. The negative issues observed in this reactor in low pH are acid requirements, accumulation of volatile fatty acids (VFAs), loss in methane production, and inhibition of methanogenesis and hydrolysis.

The results show that factors like pH, concentration of total and volatile solids, C:N ratio, COD, etc. affect the production and the quality of the biogas. The mesophilic temperature values were monitored in determining the rate of digestion and retention of the process, since temperature is very important. The mesophilic temperature affects the rate of digestion due to the outside walls of the digesters surface make direct contact with the atmosphere, hence the digesters walls absorb or loose heat depending on the temperature gradient between the digesters and its immediate environment. This implies that seasons affect the rate of heat loss or gain from the digesters, which in turn affects the microbial activities in the slurry at each stage. The bacterial involved may not play its role completely. A pH of 7 was found to be the most favorable at the mesophilic temperature range, as the organic acids were always formed during the anaerobic decomposition process [20].

In terms of flammability, the gas produced from R1-R4 reactors became flammable at different periods during the digestion. R3 and R4 were favored in terms of volume of flammable gas production of biogas and flamed on the 8th day (see figure 4).

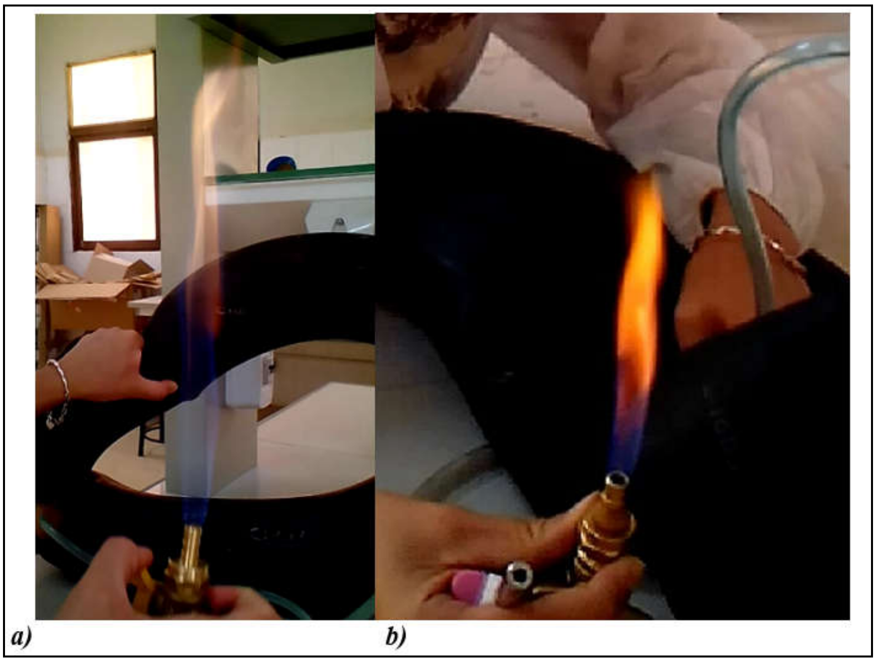

Fig.4. Flammability test for R3 and R4, respectively, on the 8th day of incubation

4. CONCLUSION

Methane and biogas production from organic fraction of kitchen wastes, dromedary dung and sewage sludge water were examined in a single-stage process. It can be concluded that:

- pH adjustment with 1M NaOH had a significant positive effect in all reactors.
- KWDD produced 34.77% CH_4, DDSSW produced 51.37% CH_4, whereas the KWDDSSW produced 64.51% CH_4 thanks to the well balanced nutrients in this media.
- A significant flammable gas was produced from R1, R2, R3 and R4 through AD. These wastes are available in our environment and can be used as a source of fuel if managed properly.
- C:N ratios of R2, R3 and R4 were found adequate to the literature (26:1, 26:1 and 27:1) because it is often suggested that C:N ratio in the substrate should be in between 20:1 to 30:1.
- pH, TS and VS, COD etc., are some of that affected the volume yield of biogas and CH_4 production.
- Digestate bio-fertilizer from the AD of R1, R2, R3 and R4 can be used to improve soil fertility. A longer HRT, a post-treatment and a final refining are recommended to avoid harmful effect on digesters system and on the environment.

It is suitable to note that the anaerobic dry co-digestion of kitchen waste and sewage sludge wastewater with camel manure is demonstrated to be an attractive solution for the protection of the environment also for the economy of the energy, but 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.

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