

Performance Characteristics of a Pilot Anaerobic Digester Fed by Farmer's Market Wastes

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Abstract

In this study, anaerobic digestion of farmer's market waste was studied in the long run and the monitoring of operating parameters is reported to provide detailed operational data for field applications. A continuous feeding of farmer's market wastes with a dry matter of 5% for 160 days were carried out using a 100 L pilot scale CSTR type anaerobic digester under mesophilic operation conditions. Hydraulic retention time (HRT) and organic loading rate (OLR) were kept around 30 days and less than 3.0 kg oDM/m³.day, respectively. During the 160 days feeding period, daily and volumetric biogas production values were reported to be 20-146 L/day and 0.3-2.0 L/L/day, respectively. This corresponds to an average biogas production 535 L/kg oDM, which means that between 40 and 100 m³ of biogas per wet ton of farmer's market waste could be produced. In conclusion, this study provides a representative operational data for field application of anaerobic digester running on farmer's market (mostly fruit and vegetables).

Keywords: Bio-methane; Farmer's market; Solid waste; Trace element

Introduction

Municipal solid waste generation exceeds 30 million tons per year in Turkey. Even though, most of the metropolitan cities in Turkey have landfills which is the main waste management option, the number of plants using either composting or anaerobic digestion techniques are quite limited in Turkey. Turkey is required to comply with EU 27 targets for landfilling of solid wastes and should gradually reduce the amount of solid waste landfilled. Turkish solid waste with more than 50% organic content is amenable for biotechnological processing either aerobically or anaerobically. Anaerobic digestion seems to be more attractive due to the high methane content of the solid waste, which is also beneficiary for Turkish renewable energy production targets in the frame of Kyoto protocol. Despite of current solid waste practices all over the world, there are still several MSW management problems in the world and the current technology is needed to be improved in order to increase the amount of generated energy as well as decreasing the amount of MSW to be landfilled. As in reported a brief history of the legislative trends in Turkey for MSW management, primitive disposal methods in the form of open dumping and discharge into surface water had been used in various parts of Turkey although strict regulations on MSW management were in place [1]. They also claimed that 70.57% of the total MSW was disposed of thereby the developments in environmental technology have been accelerated in Turkey over the last two decades in the frame of Turkey's 2023 vision and accession to EU [1]. 30% of the demand of electricity in Turkey is planned to be met from renewable energy sources by 2023 [2]. The number of sanitary landfills which is 80 in 2013 in Turkey is planned to increase 130 at the end of 2017. According to Turkish Statistical Institute values, 59.9% of MSW was disposed in municipality sanitary landfills, 0.11% of MSW was combusted with incineration (2 incineration plants), 1.15% of MSW was disposed by using a recycling method, and 37.8% of MSW was accumulated by means of municipality dumps in Turkey by 2012. Landfills, which are most widely used disposal methods, naturally produce methane, however unintended losses from landfills represent significant greenhouse gas (GHG) emissions with a global warming potential (GWP) 21 times that of carbon dioxide. In 2002, U.S. EPA reported that landfill gas leakage was responsible for 3% of total U.S. GHG emissions. Furthermore, release of gas from landfills has been estimated at 8% of atmospheric methane [3]. Global warming

and resultant climate change implications are widely recognized by the scientific community and significant decreases in carbon emissions are recommended [4]. IPCC reports indicate that in many countries, MSW management and energy system are closely linked in a way to exploit the economic and environmental benefits from this synergy. Moreover, a great part of the energy production from MSW is considered as a renewable energy source [5].

Amongst the solid waste management alternatives, biochemical conversion methods, either composting or preferably anaerobic digestion are considered to be more environment friendly in comparison to other methods such a landfilling or incineration. Especially, anaerobic digestion of the organic fraction of solid waste is much more advantageous due to the fact that both bioenergy (as methane) and organic fertilizer could simultaneously be produced while environment friendly management of MSW is carried out [6]. Furthermore, anaerobic digestion is a well-established and successfully used technology.

In this study, performance characteristics of a pilot scale anaerobic digester are presented in a way to provide detailed operational data (biogas production, DM% and oDM% removals, influent and effluent values for COD, nitrogen species, trace elements) for field applications and to promote this technology as a solution for Municipalities.

Material and Methods

Source of farmer's market wastes (FMW)

FMW used in this study was kindly provided by Municipality of Iz-

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mir Metropolitan City, Solid Waste Management Department in Izmir, Turkey on a weekly basis. FMW was first grinded and diluted down to 5% Dry Matter (DM, on the average) by adding water before use in digester. All FMW was stored in a refrigerator at +4°C until used.

Analytical methods

The parameters such as pH, DM%, oDM%, COD, TN, NO₂-N, NO₃-N, NH₄-N were measured according to "Standard Methods for the Examination of Water and Wastewater". All chemical solutions were prepared with deionized water (Milli-Q® Ultrapure Water Purification System, Millipore Corp.). Daily biogas productions were measured by Ritter Wet type gas meter. Methane content of biogas was analysed by using a Gas Chromatograph with a flame ionization detector. Trace elements were analysed by ICP-MS in accordance with APHA 3125 standard.

Experimental setup

Anaerobic digestion of MSW was carried out in a pilot scale digester with a total volume of 100 L (liquid volume 70 L). This digester is equipped with automatic control system in which temperature and mixing are controlled. Biogas production was measured by Ritter wet type gas meter on a daily basis. MSW having 5% DM after grinding and diluting with fresh water was fed daily into the digester in a way to keep the hydraulic retention time (HRT) and organic loading rates (OLR) to be around 30 days and less than 3 kg oDM/m³/day, respectively.

Results and Discussion

Characterization of farmer's market waste (FMW)

Characterization of FMW used in the study is given in Table 1. The C/N ratio of the FMW was in the range of 23-30 which is quite amenable for AD. The total nitrogen concentration was found to be in the preferable ranges. In addition, macro and micro elements were also found to be balanced which means that the digester effluents would provide the essential elements for plant growth if they are used as organic fertilizers (Table 1).

Performance evaluation of anaerobic digester (AD)

A continuous feeding of farmer's market mixture with a dry matter of 5% for 160 days were carried out using a 100 L pilot scale CSTR type anaerobic digester under mesophilic operation conditions. Hydraulic retention time (HRT) and organic loading rate (OLR) were kept around 30 days and less than 3.0 kg oDM/m³.day, respectively (Figure 1).

Daily biogas production varied between 20-146 L/day corresponding to volumetric biogas production values of between 0.3-2.0 m³/day. Considering the oDM of the feed, biogas per kg of oDM was calculated and plotted, which varied between 156-1188 L/kg oDM. This corresponds to an average biogas production of 535 L/kg oDM, which means that between 40 and 100 m³ of biogas per wet ton of farmer's market could be produced (Figure 1).

Figure 2 shows the variation of operational parameters such as DM%, oDM%, soluble and total COD in influent and effluent. Throughout the study, pH was quite stable in the digester around 7.5-8.0 there was no need to provide an external alkalinity. Depending on the feed material, the initial DM% was varied between 3 and 8% (5% on the average). At 30 day of HRT condition, 23-90% removal of DM was realized resulting an effluent DM% varying between 1-2%. In regards to oDM removal, it was monitored that 80-94% removal in oDM% was calculated. Total COD of the feed in the influent and the effluent was

Parameter	Value
pH	4.5-4.6
DM %	10.5-12.3
oDM %	80-92
TCOD (g/L)	84-101
NH ₄ ⁺ -N (mg/L)	100
TN (g/L)	3.3-3.6
C/N	23-30
Sb (mg/L)	0.0018-0.0037
Pb (mg/L)	0.0310-0.0985
T.Cr (mg/L)	0.0551-0.0963
Zn (mg/L)	2.292-2.680
Hg (mg/L)	0.0114-0.0142
Cd (mg/L)	0.0060-0.0080
Cu (mg/L)	1.382-1.746
B (mg/L)	1.741-1.825
Ni (mg/L)	0.1973-0.2366
Sn (mg/L)	0.0090-0.0141
As (mg/L)	0.0345-0.0359
Fe (mg/L)	17.15-20.19
Na (mg/L)	125.2-240.6
Ag (mg/L)	0.0125-0.0224
Co (mg/L)	0.0992-0.1113
Ba (mg/L)	0.4677-0.8074
Mn (mg/L)	1.511-2.952
Se (mg/L)	0.0116-0.0425
Al (mg/L)	9.413-10.41

Table 1: Characteristics of FMW.

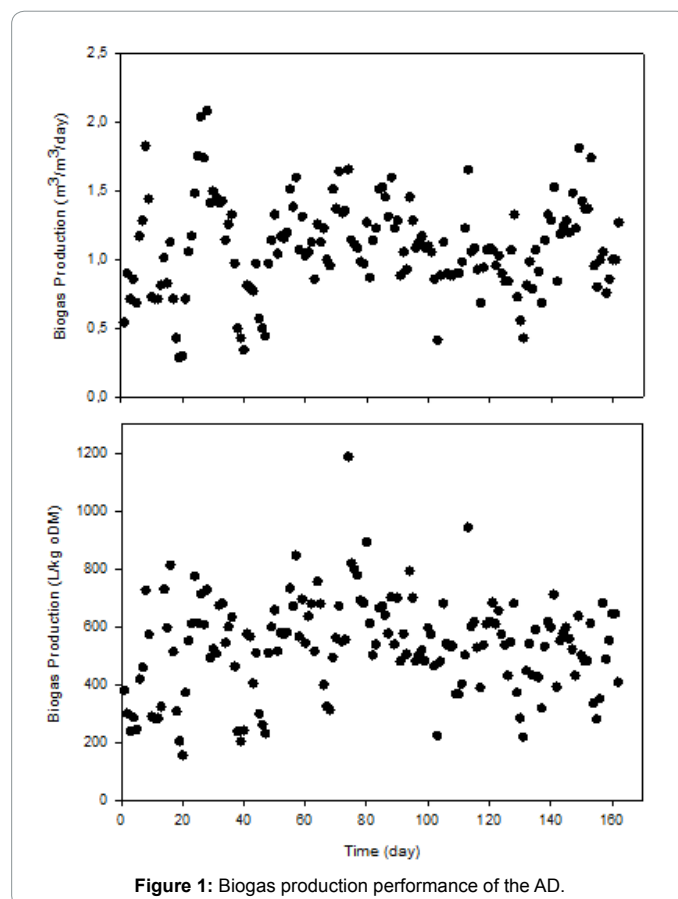


Figure 1: Biogas production performance of the AD.

between 20-92 g/L and 7-31 g/L, respectively. These results indicated that, TCOD removal varying between 52-88% was achieved. In regards to soluble COD values, it was monitored that influent and effluent SCOD values were 4-32 g/L and 1-6 g/L, respectively. SCOD removal varied between 62-95% (Figures 2 and 3).

The high nitrogen values varying between 3000-14000 mg/L in the first 60 days of operation is due to the fact that the digester was used for anaerobic digestion of chicken manure previously, TN values started to decrease following FMW feed was initiated and high nitrogen content was washed out in about 2 months. TN values were then stabilized at around 500-1000 mg/L which is more representative for FMW feed. Accordingly, $\text{NH}_4\text{-N}$ values started to decrease from a value of 8000 mg/L and then stabilized at around 300 mg/L, on the average. $\text{NH}_3\text{-N}$, which is the most critical type of TN was initially quite higher than inhibitory level but this value also started to decrease down to around 100 mg/L upon FMW feeding [7] (Figure 3).

Variations of concentration of B, Na, Al, Cr and Mn elements are given. It is seen that the B values in the feed were between 0.3-2.1 mg/L, while effluent B concentrations varied between 0.6-1.5 mg/L. High Na values resulting from previous chicken fed study sharply decreased down to 200 mg/L and effluent Na values were measured within the range of 90-330 mg/L. It is seen that, Al concentrations in the influent ranged from 0.8 to 27 mg/L. While effluent concentrations of Al were in the range of 0.2-0.8 mg/L up to the day of 120, a sharp increase in Al concentration was observed but it decreased and was stabilized at around 0.4 mg/L afterwards. It was seen that the initial level of Cr values were also high during the first 40 days of operation but then declined down to 0.05 mg/L level for both influent and effluent. Mn concentration

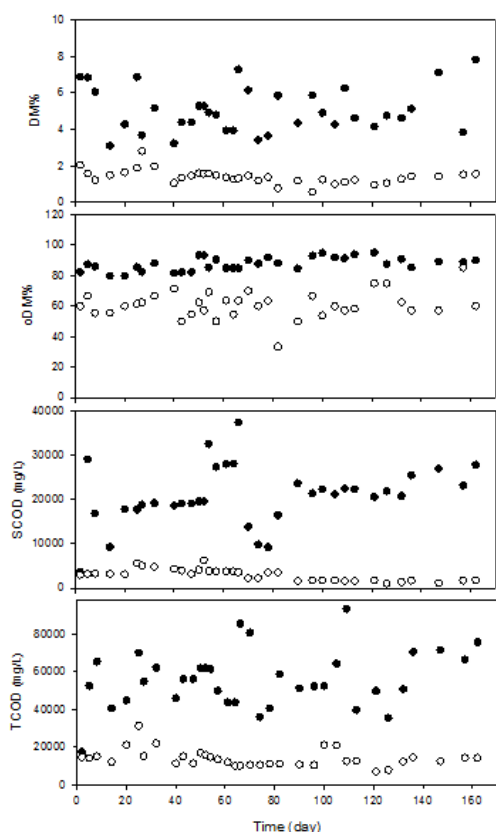


Figure 2: Variation of operational parameters: DM%, oDM%, SCOD and TCOD (● influent, ○ effluent).

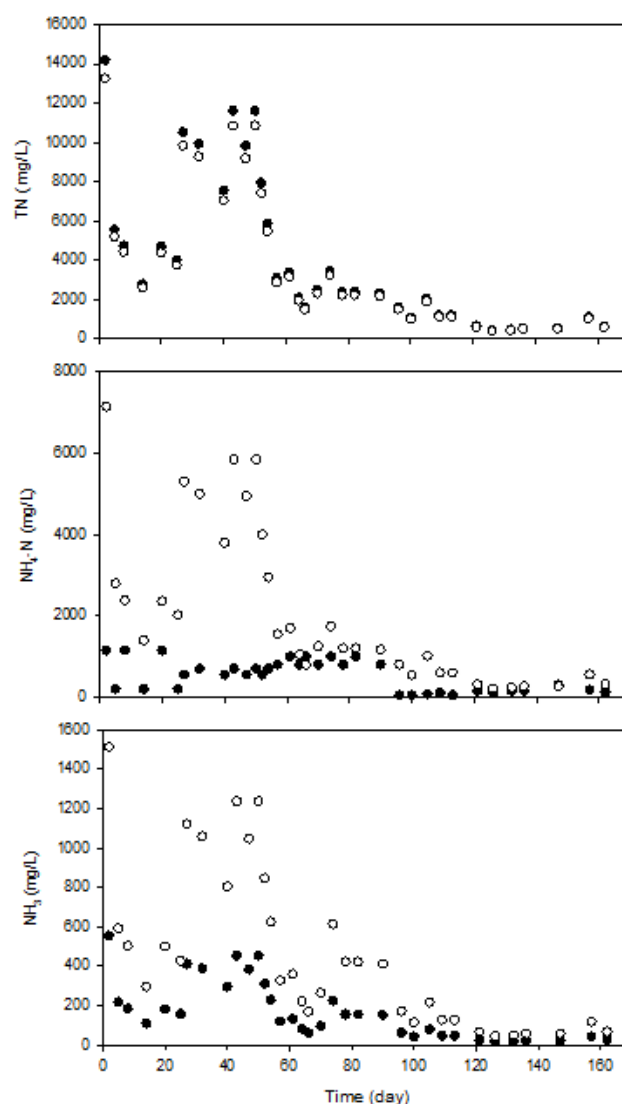


Figure 3: Variation of nitrogen species throughout the study (● influent, ○ effluent).

of the feed in the influent and the effluent was below 3 mg/L [8-15] (Figure 4).

Variations of concentration of Fe, Co, Ni, Cu and Zn elements are given. $\text{Fe}_{\text{influent}}$ and $\text{Fe}_{\text{effluent}}$ concentrations were found to vary to between 4-35 mg/L and 0.6-10 mg/L, respectively. The concentration of $\text{Co}_{\text{influent}}$ and $\text{Co}_{\text{effluent}}$ values were found to be very close to each other and varied from 0.03 to 0.3 mg/L. When the Ni, Cu and Zn graphs are examined, it is seen that $\text{Ni}_{\text{influent}}$, $\text{Cu}_{\text{influent}}$ and $\text{Zn}_{\text{influent}}$ values change in the range of 0.03-0.25, 0.07-0.1 and 0.4-2.7, respectively, and the $\text{Ni}_{\text{effluent}}$, $\text{Cu}_{\text{effluent}}$ and $\text{Zn}_{\text{effluent}}$ concentrations also decreased during 80 days, then decreased again after showing a rising trend. Accordingly, Ni effluent values decreased from the 0.25 mg/L to 0.01 mg/L and then increased up to 0.28 mg/L and were measured at about 0.03 mg/L in the last 20 days of the study. $\text{Cu}_{\text{effluent}}$ concentration decreased from 0.8 mg/L to 0.2 mg/L, then values increased to 1.1 mg/L and after the 120th day decreased to 0.06 mg/L again. $\text{Zn}_{\text{effluent}}$ values similarly decreased from the levels of 3.2 mg/L to 0.3 mg/L for the first 80 days of operation, after

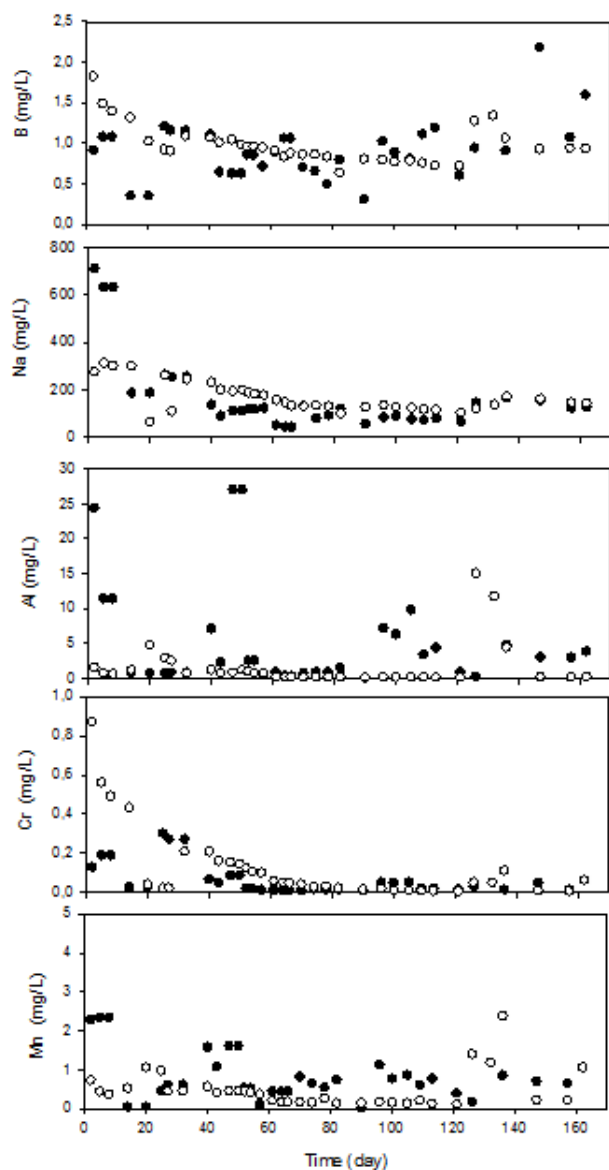


Figure 4: Variations of concentration of B, Na, Al, Cr and Mn elements (● influent, ○ effluent).

increased to 2.7 mg/L and then the levels of Zn_{effluent} was determined to be 0.3 mg/L (Figure 5).

Variations of concentration of As, Se, Cd, Sb and Ba elements are given. As_{influent} and As_{effluent} concentrations were seen to vary between 0.008-0.1 mg/L and 0.007-0.05 mg/L, respectively. The concentration of Se_{influent} and Se_{effluent} values were found to be very close to each other and varied from 0.02 to 0.2 mg/L. The concentration of Cd_{influent} and Cd_{effluent} values changed between 0.001-0.02 mg/L and 0.002-0.03 mg/L, respectively. Sb_{influent} and Sb_{effluent} values varied from 0.001-0.005 mg/L. It was seen that the Ba_{influent} concentration rised from 0.2 mg/L to 1.2 mg/L, whereas the Ba_{effluent} values were measured between 0.1-0.7 mg/L except for a few points where Ba concentrations jumped upto 1.5 mg/L (Figure 6).

Influent and effluent concentrations of Hg, Pb, Ag and Sn. Hg_{influent} and Hg_{effluent} were in the range of 0.02-0.3 mg/L and 0.01-0.7 mg/L,

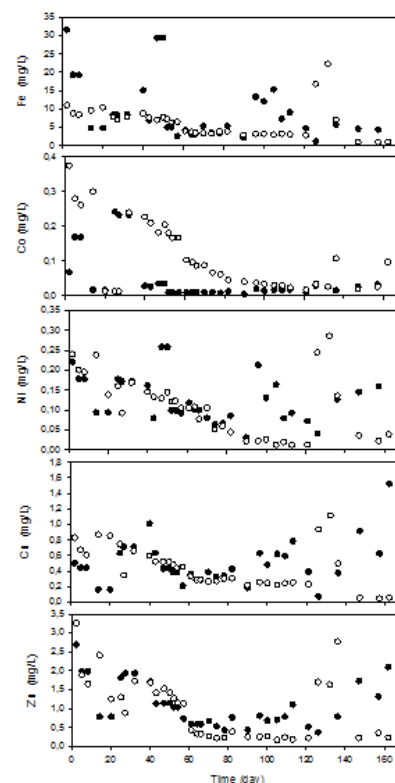


Figure 5: Variations of concentration of Fe, Co, Ni, Cu and Zn elements (● influent, ○ effluent).

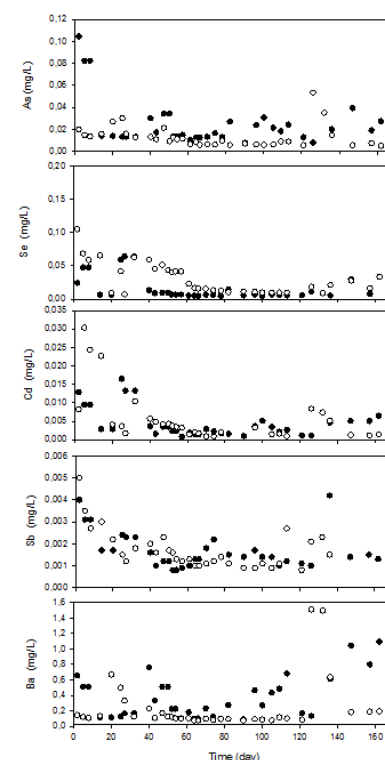


Figure 6: Variations of concentration of As, Se, Cd, Sb and Ba elements (● influent, ○ effluent).

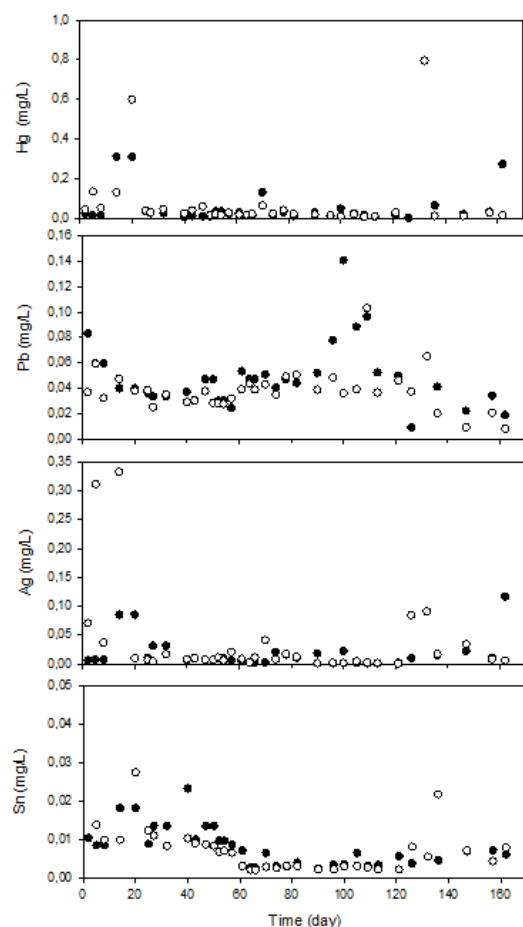


Figure 7: Variations of concentration of Hg, Pb, Ag and Sn elements (● influent, ○ effluent).

respectively. Influent and effluent Pb concentrations were close to each other and measured as Pb_{influent} : 0.01-0.14 mg/L and Pb_{effluent} : 0.006-0.1 mg/L. In regards to Ag measurements, except for two high values in the beginning of the operational period, Ag concentrations in the influent were in the range of 0.005-0.12 mg/L, whereas effluent concentration varied between 0.003-0.33 mg/L. Similarly, Sn measurements indicated that Sn concentrations were low both in influent (0.003-0.023 mg/L) and effluent (0.002-0.03 mg/L) in parallel to each other (Figure 7).

Conclusion

Anaerobic digestion of organic fraction of FMW is able to produce significant amount of biogas which has a great potential to be used as renewable and environment friendly energy alternative. This study

provides a representative operational data for field application of anaerobic digester running on farmer's market wastes. The results also provide precious data in regards to management of the digestate, especially from the point view of residual organics and trace metal content.

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