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Use Of a Novel Bioreactor Configuration in The Form of High Solid Digestion For Municipal Organic Wastes at Pilot Scale

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Abstract

The objective of this study was to investigate the performance and process stability of a novel dry anaerobic digestion system. For this purpose, a dry anaerobic digester (100 L) with percolate tank (200 L) was designed at pilot scale. Municipal solid wastes were fed into the dry fermentation unit and system was operated with intermittent recycling of leachate through percolation unit back to the dry fermentation unit twice a day. Gas production in both unit was recorded daily and gas content and leachate analysis were carried out periodically. A batch feeding of solid waste (17.5 kg waste) having less than 5 cm particle size with a dry matter of 13% and organic dry matter of 85% was carried out and process was operated for 60 days. Results indicated that 560 L methane per kg organic dry matter was produced. This corresponds to biogas production 119 m3 per ton of wet solid waste. It was also observed that the main gas production took place in percolate tank and the solid digester acted as a hydrolysis and acid reactor indicated by the low gas production and acidic leachate characteristics. There were also almost no digestate generation which eliminates costly post treatment units before the discharge of digestate, which is a critical problem for wet digestion counterpart.

Key words

Anaerobic digestion, high solid fermentation, methane, municipal solid waste

1. INTRODUCTION

Industrialization and rapid urbanization has increased significantly the generation of municipal solid wastes (MSW) and as in many developing countries it is a big environmental problem for Turkey. In 2014, MSW generation rate was 1.08 kg/cap.day, 28 million tons of MSW generated, and this waste was landfilled either in sanitary landfills (63.6%) or dumpsites (35.5%), composted (4%) and disposed with other ways (5%) [1]. Typical MSW composition in Turkey contains high biodegradable organic fraction (40-75%) as it can be seen in Table 1 [2].

On the other hand, MSW management has been a pressure point for Turkey while being a candidate country for EU accession and EU 27 targets .In order to decrease the amount of organic biodegradable waste sent to landfill sites and to set up a waste management system, most of the EU waste management directives have been transposed into Turkey's national legislation. Therefore the reduction of biodegradable waste amounts which is landfilled and proper treatment of MSW is an important task for Turkey [3].

Table 1.Composition of MSW in Turkey

Components	Range in weight (%)
Organics	40-65
Paper/cardboard	7-18
Plastics	5-14
Metal	1-6
Glass	2-6
Others	7-24

Anaerobic digestion (AD) is a promising solution as it is a biological treatment capable to decompose the organic matter under oxygen free conditions [4]. Furthermore, the end product of AD includes biogas (60–70% methane) which is a renewable energy resources, and the effluent which is an organic residue rich in nitrogen can be used as soil conditioner or fertilizer [5,6]. AD process is based on four steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis [7] and can be classified based on operating parameters and reactor design [4]. Depending on the total solid (TS) concentration of the feedstock the AD process can be divided into wet (<10% TS) and dry (>10% TS) digestion processes [8].

Compared to wet digestion, dry digestion, also known as ‘‘high-solid’’ anaerobic processes [8] is advantageous in terms of smaller reactor volume, lower energy consumption for heating, higher volumetric methane productivity [6], less wastewater generation, low-moisture digestate that is easier to handle and lower total energy loss [4]. However, in dry digestion due to the contact between microorganism and feedstock is poor the biogas yield is generally low and there is a high tendency to inhibition lead by accumulation of ammonia and volatile fatty acids (VFAs) [9]. The digestate or leachate of dry AD can be recycled to inoculate the fresh feedstock on the purpose of improving the biogas yield [10]. Systems that recycle leachate into the reactor vessel are called percolation systems. Leachate recycling approach provides a good transportation for microorganism throughout the digester and prevent the inhibition caused by accumulation of VFAs and ammonia [4].

The objectives of this study was to investigate the process performance and stability of a novel anaerobic digester configuration which employs dry fermentation of municipal solid wastes.

2. MATERIALS AND METHODS

2.1. Feedstock and Inoculum

MSW were obtained from Izmir Metropolitan City, Solid Waste Management Department in Izmir, Turkey and it mainly consisted of seasonal vegetable and fruits. The wastes were whittled to have a particle size around 5 cm before filled in reactor . Representative samples of MSW (small pieces taken from each fruit and vegetable) were crushed using an electrical blender and used to perform analytical analysis. Anaerobic inoculum was taken from an upflow anaerobic sludge blanket (UASB) reactor fed with wastewater of a beer factory located in Izmir.

2.2. Process Description

The process consist of a batch dry anaerobic reactor with 100 L total volume and a percolate tank with 200 L total volume. Inside the reactor there was a stainless steel basket which has holes at the bottom and the side and keeps the solid material inside reactor. On the top of the reactor the inoculum-percolate distribution device which is basically a perforated plate was placed and allowed the distribution of percolate over the feedstock. The temperature and humidity probe were also set on the top of the reactor.

In the beginning of the study the percolate tank was filled with the liquid anaerobic inoculum equipped with an agitator and a pump. Once a day this liquid inoculum was sprayed on the feedstock in the dry digester, passed through the substrate stack and reached into the percolate tank from the pipeline which is placed between the bottom of the dry digester and percolate tank (leachate circulation line). A sampling point was located on the leachate circulation line, every 2 or 3 days, samples from leachate were taken from this line and analyzed for VFA and total ammonia nitrogen (TAN).

The percolate tank and digester were heated by hot water through the heating pipe installed inside the tanks to keep the temperature at 37 °C and isolated for heat preservation. Biogas production was measured by a drum type gas meter for both dry digester and percolate tank, and biogas sampling was done from the line between reactor and gas meter.

2.3. Analytical Methods

VS and TS contents were analyzed according to the APHA Standard Methods for the Examination of Water and Wastewater. TAN was determined using a colorimetric method with an ammonia nitrogen kit, and a spectrofotmeter. VFAs in the AD leachate were measured using a gas chromatography (GC). Leachate samples were centrifuged then supernatant was filtered through 0,45 μm nylon syringe filter for GC analysis. The volume of biogas was measured by a drum type gas meter (Ritter, Germany) and the composition of biogas (H_2, CH_4 and CO_2) was analyzed by Agilent gas chromatograph equipped with a flame ionization detector and a DB-FFAP 30 m × 0.32 mm × 0.25 mm capillary column.

3. RESULTS AND DISCUSSION

3.1. Characteristics of MSW

The characteristics of MSW and inoculum used in this study are shown in Table 2. As the content of MSW varied depending on different seasons, in summer MSW consist of mostly juicy fruits and vegetables therefore TS of the MSW used in this study was 13%, and VS was 85% of TS respectively.

Table 2.Characteristics of MSW

Parameter	MSW
TS (%)	13
VS (%TS)	85
NH4+-N(g/L)	0,1
pH	4.55

Fruit and vegetable wastes was characterized by an acid pH (pH of 4.55). It has been reported that due to the hydrolytic and fermentative/acidogenic processes are in action during storage in bin containers before its collection OFMSW has low pH values which is caused by the high VFA concentration [11].

3.2. Anaerobic Dry Digestion: Leachate Analyses

The dry fermenter was filled with the MSW and closed with gas tight cap. The inoculum was sprayed on MSW everyday for thirty seconds. A representative sample of leachate was taken periodically to perform the chemical characterization and a pH probe was placed in the circulation pipeline to monitor pH changes of leachate. Fig 1 shows the pH and total VFA trends in the leachate.

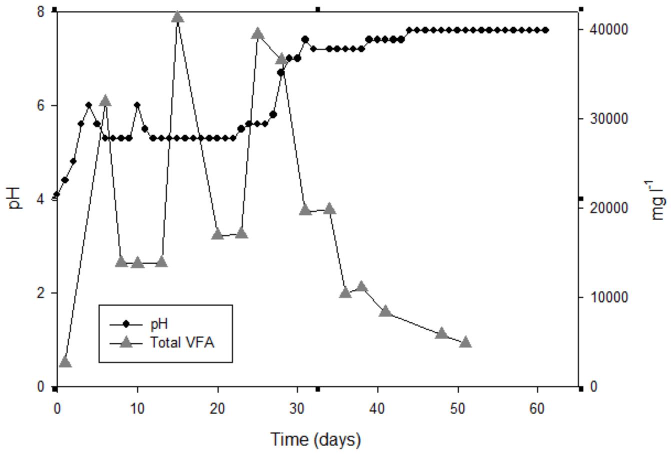

Figure 1. VFA and pH trends in the leachate

VFAs namely, acetic acid, propionic acid, butyric acid, isobutyric acid, valeric acid and isovaleric acid are intermediates produced during the hydrolysis and acidogenesis steps of anaerobic digestion [12]. The first leachate was characterized with low total VFA concentration. As the contact between microorganisms and substrate increase microbial activity was activated and in the sixth day of the process a sharp increase occurred in total VFAs with a concentration of 32000 mg l^{-1} and this VFAs consumed and flushed to percolate tank. However two other peaks in total VFAs occurred on day 15 and 25 with the concentration of 41000 mg l^{-1} and 40000 mg l^{-1}, respectively. The pH values of the leachate was around 4 in the beginning of the experiment. Afterward the pH value of leachate reached 5.5 in following four days and remained around 5.5-6 between days 4 and 28 due to the high VFA concentrations in leachate. From this moment the total VFA concentration in the leachate showed a decreasing trend and as total VFA concentrations decreased in the leachate the pH values of the leachate increased and reached to neutral values(7.0). The optimum pH of hydrolysis and acidogenesis has been reported as being between 5.5-6,0 and the optimum pH of methanogenesis is over 7.0 [12]. Due to the low pH values which is caused by high VFAs concentrations during the first 30 days of the process methanogenic activity in the dry digester might be inhibited and resulted with the low methane content of the biogas in dry digester It is reported that interactions between VFAs and pH may cause an inhibition where the process runs stably but with a lower methane yield[13].

The chemical compositions of the VFAs of the leachate is also shown in Fig 2. During the first days of the process, the leachate was rich in caproic acid, butyric acid, valeric acid and propiyonic acid. Acetic acid is the major substrate of the methane forming bacteria in an anaerobic digester [14] and it started to represented after the 30th day of the process by degredation of butyric, caproic and propionic acid [14] to acetic acid. Formic acid and heptanoic acid were also detected at relatively low concentrations.

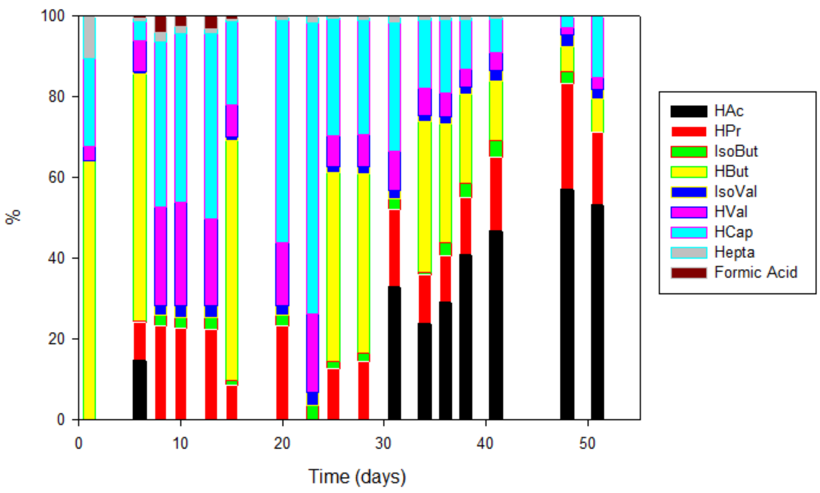

Figure 2. Individual VFA speciation ranges in the leachate

The TAN concentration of the leachate is shown in Fig 3. During the experiment TAN concentration remained under 150 mg l^{-1} which is reasonable for the AD process stability. It is reported that nitrogen is an essential nutrient for the anaerobic microorganisms and TAN concentrations below 200 mg l^{-1} are considered to be beneficial while concentrations exceeding 1500 mg l^{-1} can be moderately inhibitory [15]. As it can be seen in Fig 4 TAN concentrations stayed between beneficial range and no inhibition effect lead by ammonia accumulation occurred during the study.

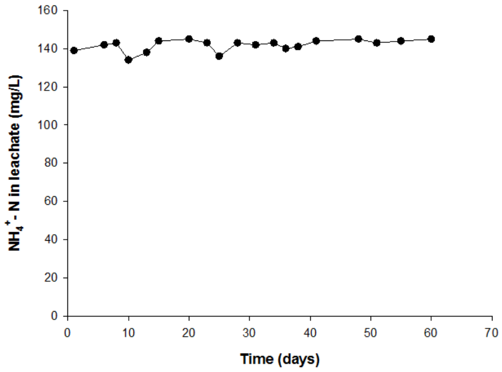

Figure 3. TAN concentration in leachate

3.3. Biogas and Methane Production

The start-up of the process followed different trends in percolate tank and dry digester (Figure 4). During first four days while big amounts of biogas was produced in percolate tank there was no biogas production in dry digester. The total biogas produced in percolate tank for first four days was 880 L which is the 50% of the total biogas production value reached after 60 days. It is reported that the fruit and vegetable waste has a big part of easily digestible fraction, which might produce excessive VFAs at the beginning of the dry digestion [16]. This soluble VFA leached from dry digester washed into the percolate tank and digested to biogas which might be the reason of high amount of biogas production in percolate tank in the first four days. However, the biogas production of the percolate tank decreased to a stable level after 10 days and after 40 days the biogas production progressively decreased and reached values around 5-3.

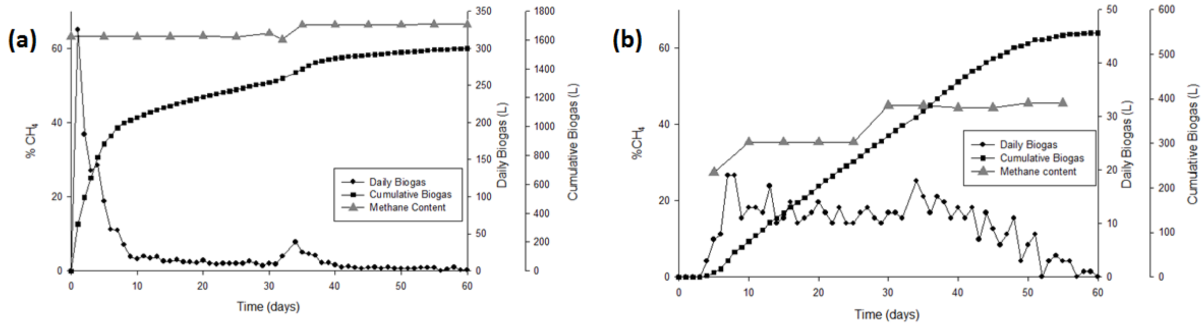

Figure 4. Daily and cumulative biogas production and methane content of biogas: (a)Percolate tank; (b) Dry digester

Fig. 4b shows that a lag phase of 4 days occurred at dry digester. The degredation of the feedstock depends on the connection between the substrate and microorganism and in the liquid digester, this movement is mainly done by mixing the whole substrate or by passing liquid substrate to microorganism surface [16]. In dry digester used in this study this connection was done by the percolate circulation and in the beginning hence the big particle size and highly porous structure of substrate stack the connection between microorganisms and feedstock was not done efficiently. It is reported that the percolate recirculation at a high flow rate allowed accelerating the solid–liquid mass transfer and increase the biogas production dramatically. It is also shown that increasing the percolate recirculation rate in intermittent and short recirculation operations improves the stability and speed of the dry anaerobic digestion [17]. Afterward the biogas production of the dry digester increased and reached to a stable level and the digester showed a steady biogas production for 40 days.

3.4. Overall Process Performance

The biogas and methane production of dry digester and percolate tank is shown in Table 3. Dry digester and percolate tank totally produced biogas of 2095 L, of which 550 L of biogas produced from dry digester, and 1545 L of biogas produced from the percolate tank which is the 75% of total biogas production.

These results indicated that a big amount of VFAs produced in dry digester and washed into the percolate tank with the recirculation of percolate and were digested into biogas. During the first 40 days, the process was separated into two-phase system of hydrolysis and acetogenesis in dry digester and methanogenesis in percolate tank. However, with recirculation of percolate the methanogens was irrigated into the digester and biogas and methane was produced both in percolate tank and dry digester. Depending on biogas and methane production values the AD efficiency of the percolate tank was much higher than dry digester. Some studies also reported the same results that two-phase dry AD has advantages of more stable processing [16,17].

Table 3. Biogas and Methane production of percolate tank and digester

	Biogas production (L)	CH_4 production (L)
Percolate Tank	1545	875
Dry Digester	550	210
Total	2095	1085

The specific biogas and methane yields reached after 60 days were 1085 L biogas kg^{-1} VS and 560 L CH_4 kg^{-1} VS, respectively. It is reported that the biogas yield of fruit and vegetable wastes varied from 650-700 L biogas kg^{-1} VS depending on different TS values [17]. It is also investigated that the methane yield of different content of solid organic wastes varied from 200-850 L CH_4 kg^{-1} VS [18]. Compared with literatures, the results showed that biogas yield in this experiment much more higher than literature values, methane yield was in an avarage range.

4. CONCLUSIONS

The objective of this study was to investigate the performance and process stability of a novel dry anaerobic digestion system and has demonstrated that the system is technically feasible for high solid anaerobic digestion of MSW.

The results also showed that the main gas production took place in percolate tank and the solid digester acted as a hydrolysis and acid reactor indicated by the low gas production and acidic leachate characteristics. There were also almost no digestate generation which eliminates costly post treatment units before the discharge of digestate, which is a critical problem for wet digestion counterpart.

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BIOGRAPHY

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