Renewable energy production from organic fraction of municipal solid waste through two-phase anaerobic digestion

Eylem DOĞAN, Göksel N. DEMİRER

Middle East Technical University, Department of Environmental Engineering, 06531,

Ankara, TURKEY

Abstract

The organic fraction of municipal solid waste (OFMSW) can be a significant energy source for renewable energy generation. The total production of municipal solid waste (MSW) in Turkey was 25 million tones per year. Anaerobic digestion (AD) process may be a solution to the problems of energy demand and waste management since it provides biomethanation along with waste stabilization. AD can be operated in single or two phase configurations. Two-phase processes have some advantages over one phase systems in terms of selection of microorganisms, process efficiency, and reactor size. In this study, biochemical methane production (BMP) experiments were performed in order to investigate whether phase separation enhanced the efficiency of methanogenic activity or not. The performances were compared in terms of tCOD and VS reductions, and cumulative gas production. The experimental results indicated that 10% and 23% increases in tCOD and VS removals were achieved, respectively, by phase separation. The acetic and propionic acids were not detected in the reactors which was an indication of successful methanization.

Keywords

Anaerobic, biogas, organic fraction of municipal solid waste, phase separation

1 Introduction

The demand for energy and industrial materials are on a significant rise parallel to the rapid industrialization and population growth in many developing countries. Therefore, alternative energy sources need to be investigated, since the conventional energy sources are being exhausted rapidly (Bhattacharyya et al., 2008). Municipal solid waste (MSW), with its significant organic fraction (30-50%), can be an alternative energy source for power generation by biomethanation process. The total production of MSW was 25 million tones per year for 2004 in Turkey which created a significant energy content and in this context; it must be used for the energy generation (TURKSTAT 2007; Dogan et al., 2008). Therefore, anaerobic digestion (AD) process may be a solution to the problems of energy demand and waste management because it provides biomethanation along with waste stabilization. Through AD, organics are decomposed by specialized bacteria in an oxygen-depleted environment to produce biogas and stable solid. Each of these products can be used for beneficial purposes; the biogas, which consists of up to 65% methane, can be combusted in a cogeneration unit and produce green energy. The solid digestate can be used as an organic soil amendment.

AD can be operated in single or two phase configurations. Single phase incorporates both acid formation and methane production in the same reactor, while two phase operation attempts to separate acid formation from methane production, usually by providing two reactors (Speece, 1996). Two-phase processes have some advantages over one phase systems. First of all, the selection and enrichment of different bacteria are achieved and the control of acidification phase enhances the stability of the system by preventing overloads that may affect methanogens. Another advantage is that the tank volumes are smaller due to the applicability of short hydraulic retention times and therefore, the system is more cost effective. Last advantage of the separation is that high solid containing wastes, which may be problematic, are liquefied through the acidification step and the application of this step increases the efficiency of the system. On the other hand, conventional one-phase digestion is not effective for wastes with high solid content since significant increase in fluid and digester volume is observed during one-phase operation systems (Demirer and Chen, 2005). In addition, the conventional systems applied to produce methane from organic waste are often inefficient, time-consuming and costly. The production of volatile fatty acids (VFA) proceeds at a much higher rate when concentrated soluble or high solid feeds are used in these systems. Therefore, the conversion of VFAs to methane does not take place due to acid accumulation, pH drop and consequent inhibition of methanogenesis in the one phase systems (Ghosh et al., 1975; Ghosh, 1987). This is why the application was shifted from single phase to two phase configurations in time.

In this study, biochemical methane production (BMP) experiments were performed in order to show the applicability of the phase separation for the enhancement of the gas production from OFMSW. For this purpose, one acidifying reactor was operated for 30 days under optimum conditions (with organic loading rate of 15 g VS/L.day, hydraulic retention time of 2 days and pH value of 5.5). These conditions were determined beforehand by operating five acidifying reactors with three different organic loads and pH values. The effluents of the acidifying reactor and raw solid waste were used separately as feed for the operation of the BMP reactors and the results were compared. Therefore, the objective of this study was to investigate the effectiveness of two-phase system in the enhancement of biogas production during the treatment of OFMWS.

2 Materials and Methods

2.1 Organic Fraction of Municipal Solid Waste and Anaerobic Seed Culture

The organic fraction of municipal waste (OFMSW) used in this study was composed of food and kitchen wastes collected from houses and, vegetable and fruit wastes collected from markets. All these wastes were separated from glasses, plastic materials and were coarsely shredded in a grinder having an average size of about 4 mm. Required amount of paper, which was kept in water for a week, was added to this mixture in order to simulate the municipal solid waste composition in Turkey, and thus to have a paper content of %6.47 (Table 1) (TURKSTAT, 2007). As a final step, all the waste was well mixed manually for homogenization. The waste was stored in deep-freeze at -20 ^{0}C prior to use for the prevention bacteriological activity and the characteristics of it are presented in Table 2.

Table 1 Typical solid waste composition in Turkey

PARAMETER	**VALUE** (%)
Textile	0.56
Metal	1.13
Glass	2.12
Plastic	2.55
Paper	6.47
Organic	64.15
Others (ash, slag, inert materials)	23.02

The mixed anaerobic sludge culture from the anaerobic digesters of Ankara Central Wastewater Treatment Plant was used as inoculum. The volatile suspended solid (VSS) concentration of the sludge was 8017 ± 1438 mg VSS/L. The seed sludge was screened through a 1 mm size sieve before used in order to remove debris, fibers.

Table 2 Characterization of the OFMSW used.

PARAMETER	VALUE [a]
Density (kg/m^3)	1022.0±8.5
Bulk density (kg/m^3)	963.0±9.2
Total solids (g/kg)	299.0±6.4
Volatile solids (g/kg)	262.0±3.7
Total COD (g/kg)	241.0±2.5
TKN (g/kg)	4.00±0.50
Total P (g/kg)	2.00±0.10
pH	5.18±0.20

[a] Data are expressed as mean ± SD of the three replicates.

2.2 Experimental Set-up

At the beginning of this study, one acidifying fed-batch type continuous stirred tank reactor (CSTR) was operated under the determined optimum acidification conditions. After this reactor reached to the steady state, its acidified effluents were used as substrate for the half of the reactors in the BMP experiment. On the other hand, the remaining half of the BMP reactors was directly fed by the raw solid waste. The BMP reactors containing acidified solid waste served as the methane reactor of a two-phase system, whereas the ones fed by the raw solid waste were used as one- phase reactors (Figure 1).

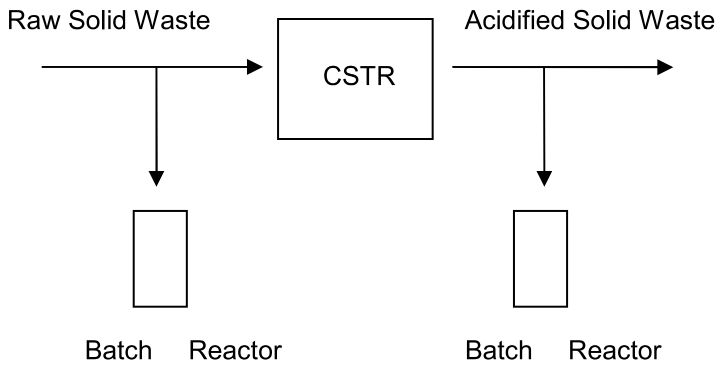

Figure 1 Schematic presentation of the experimental set up

In the BMP experiment, 250 ml serum bottles with effective volume of 150 mL were used as batch reactors. The reactors which contained basal medium (BM) were flushed with N_2 gas for 5 min to maintain anaerobic conditions after seeding. All the reactors were sealed with rubber stoppers and plastic screw-caps, and continuous mixing was applied at 200 rpm. The reactors were operated for 40 days at 35 ± 1 ^{0}C and the gas production was measured with water replacement device. The reactors had controls and blanks; and were operated in duplicates. Two total COD (tCOD) concentrations (5000 mg/L and 4000 mg/L) were applied for different reactors simply to achieve food to microorganism (F/M) ratios ranged between 0.2-1.35; suitable for the BMP tests as stated in the literature (Prashanth et al, 2006). Higher tCOD concentrations were not applied since any ratio over the range might have an inhibitory effect on the reactors due to overloading. Hence, the reactors having tCOD value of 5000 mg/L and 4000 mg/L were coded as 1 and 2, respectively (Table 3).

Table 3 Experimental set-up information of the BMP reactors

Reactor	**Substrate**	**COD (mg/L)**
A1	Acidified solid waste	5000
A2	Acidified solid waste	4000
N1	Raw solid waste	5000
N2	Raw solid waste	4000
Control	-	-

2.3 Analytical Methods

Volatile fatty acid (VFA) measurements were conducted by using a Trace Gas Chromatograph (GC) Ultra (Thermo Co.) with a flame ionization detector (FID) fitted with a Zebron ZB-FFAP column, having length of 30 m, internal diameter of 0.25 mm and film thickness of 0.25 µm, injector temperature of 250 ^{0}C. Operating conditions were: injector temperature, 250 °C; FID temperature, 350 °C; oven temperature program: 100–250 °C (8°C /min); duration, 2 min. Helium was the carrier gas in the system. Formic acid (%98, Riedel-de Haen, Germany) was added to the filtered samples in order to decrease the pH below 3 for the conversion of volatile fatty acids to their undissociated form.

The pH values were measured by pH-meter and pH probe (Hanna Instruments HI 8314 Membrane). The TS, VS, VSS, TP and TKN measurements were performed according to the Standard Methods 2540B, 2540E, 2540D, 4500-P B-E and 4500-N_{org} B, respectively (APHA, 2005).

3 Results and Discussions

Biogas production is one of the significant indicators used in the evaluation of the reactor performance. Figure 2. depicts the cumulative biogas productions measured during the course of operation. The results indicated that acidification step enhanced the biogas productions and the production values reached to 265 mL and 160 mL in A1 and N1, whereas the values measured as 212 mL and 110 mL for A2 and N2, respectively. Moreover, higher productions were observed in A1 and N1 clearly; that is, the reactors with higher influent tCOD loads ended up higher biogas productions in the final as stated in the literature (. Demirer et al. 2000; Uzal et al., 2003).

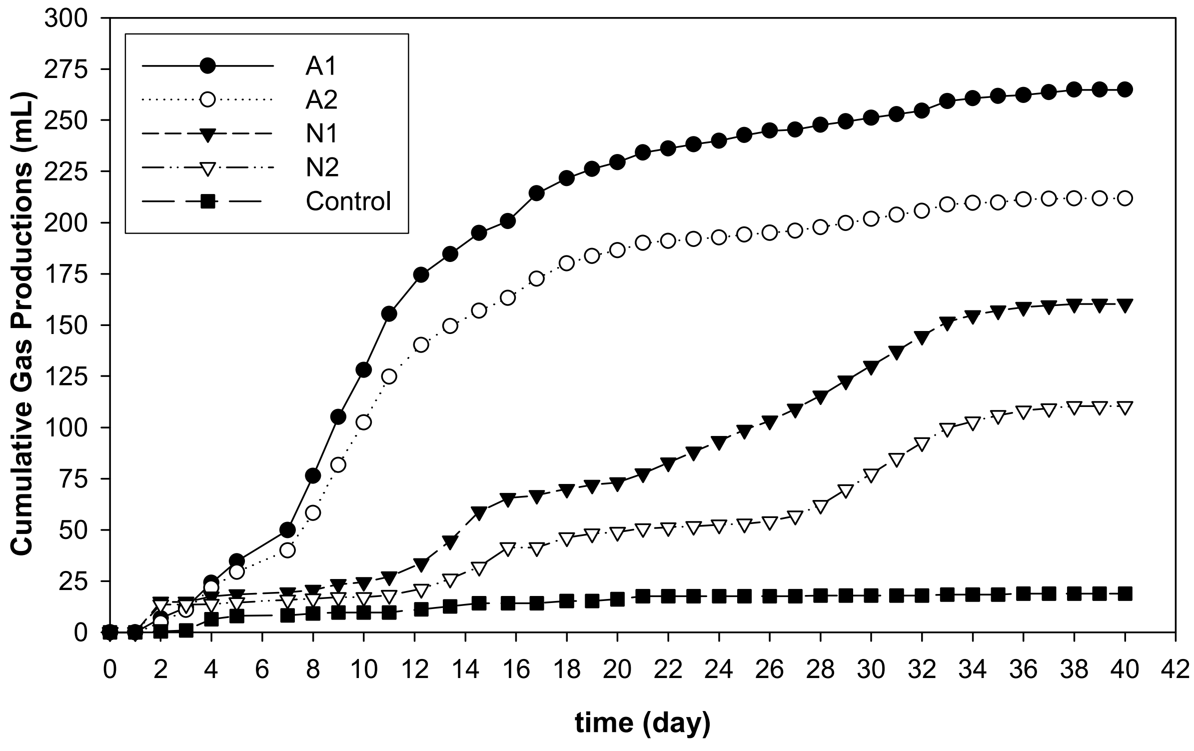

Figure 2 Cumulative gas productions measured throughout the experiments

On the other hand, the tCOD and VS reductions were presented in Figure 3. The removals in tCOD were calculated as 39% and 29% for the reactors A1 and N1, and the percentages were 36 % and 27% for A2 and N2, respectively. The reductions were higher in A1 and A2 since the waste used to feed these reactors was converted to the organic acids in the acidification process applied prior to BMP experiment and these readily biodegradable acids were directly utilized by the methanogenic microorganisms in the batch reactors. Therefore, the removal was more likely to be achieved due to the direct utilization of the acids. Clearly, the conversion of raw solid waste into the organic acids was achieved in the reactors N1 and N2 first, and then conversion to the biogas took place. Moreover, the activity of the acidogenic bacteria might have affected the methanogens adversely which resulted in lower process efficiencies than A1 and A2.

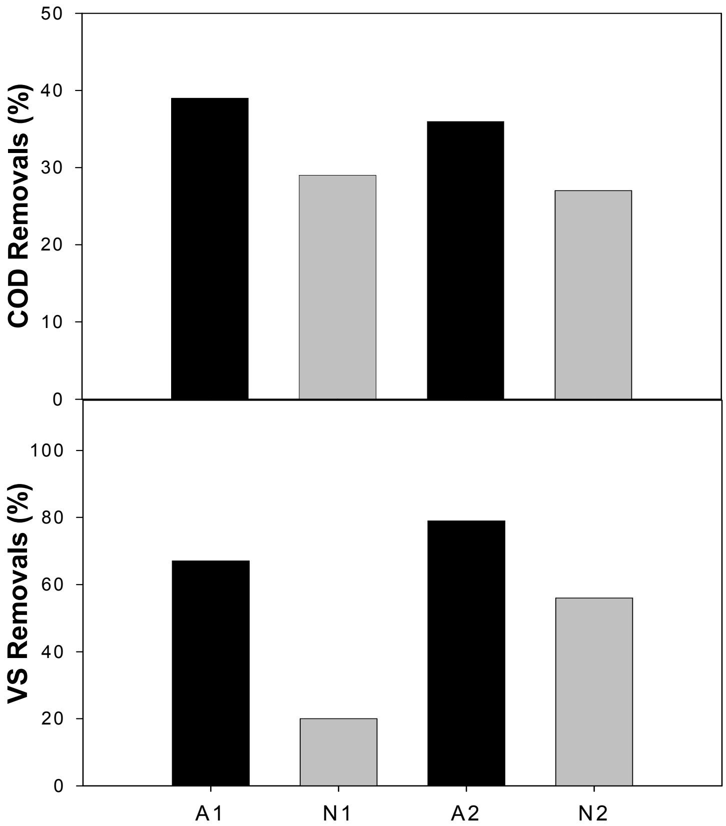

Figure 3 tCOD and VS reductions observed in the reactors

VS removal efficiencies estimated as 67% and 21% for the reactors A1 and N1, respectively in the study; yet the percentages were 79% and 56% for A2 and N2, respectively. Higher removals were achieved again in the reactors A1 and A2 due to the reasons stated above. The results also supported by the biogas production profiles observed between the reactors. The phase separation enhanced the removal of volatile organics in the reactors and in turn the biogas production. At the end, the results revealed that phase separation improved the performance of the methane reactor in terms of tCOD, VS removals and biogas productions as stated in the literature studies (Demirer and Chen, 2004; 2005)

Total VFA (tVFA) concentrations were also analyzed at the end of the operational period and the values were determined as 30, 146, 99, and 197 mg (as Hac)/L for reactors

A1, N1, A2 and N2, respectively (Figure 4). It has to be underlined that lower acid concentrations were measured in the reactors A1 and A2 than N1 and N2, and the reason might have probably been the utilization of them by microorganisms. The tCOD removals in the reactors were also consistent with the tVFA concentrations. The reactors having higher tCOD reductions had lower acid concentrations which meant that the utilization of organic acids brought about the reduction in the tCOD values.

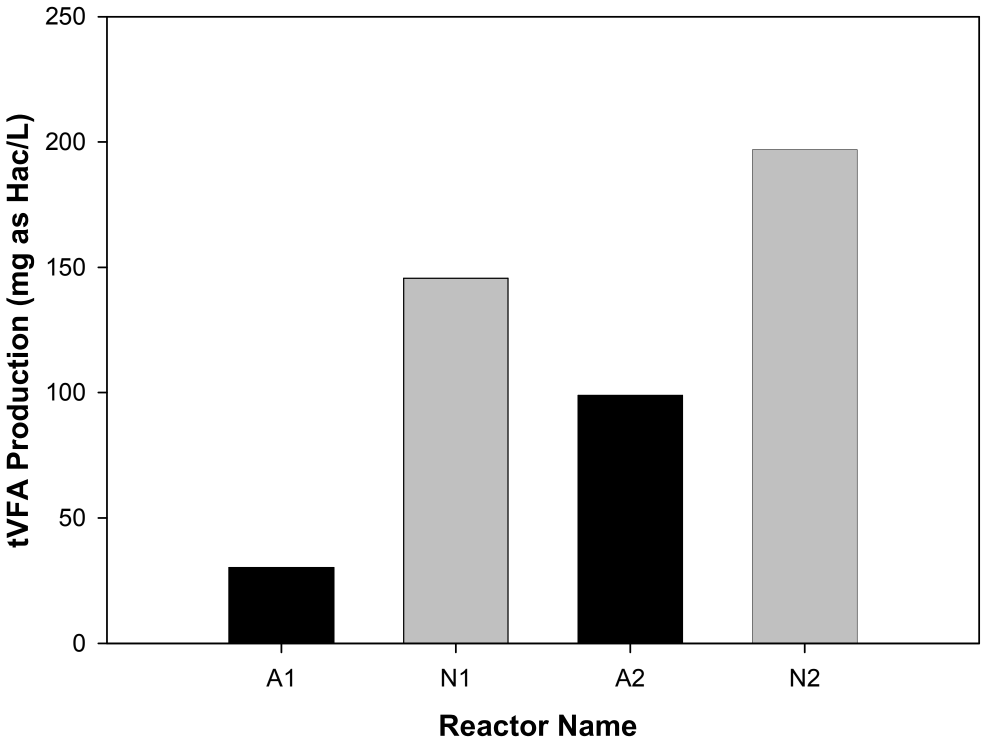

Figure 4 tVFA production of the reactors

When the VFA compositions were analyzed, the main organic acids appeared to be butyric and isobutyric for all the reactors; and isovaleric for the reactors N1 and N2 (Figure 5). There was no acetic acid content in the reactors and the reason was probably the utilization in methanogenesis step. In addition, Viturtia et al. (1995) stated that lower acetic acid concentrations, compared with other acids, were the indication of methanogenic activity; hence, methanogenic activity, which resulted in biogas production, took place in this study.

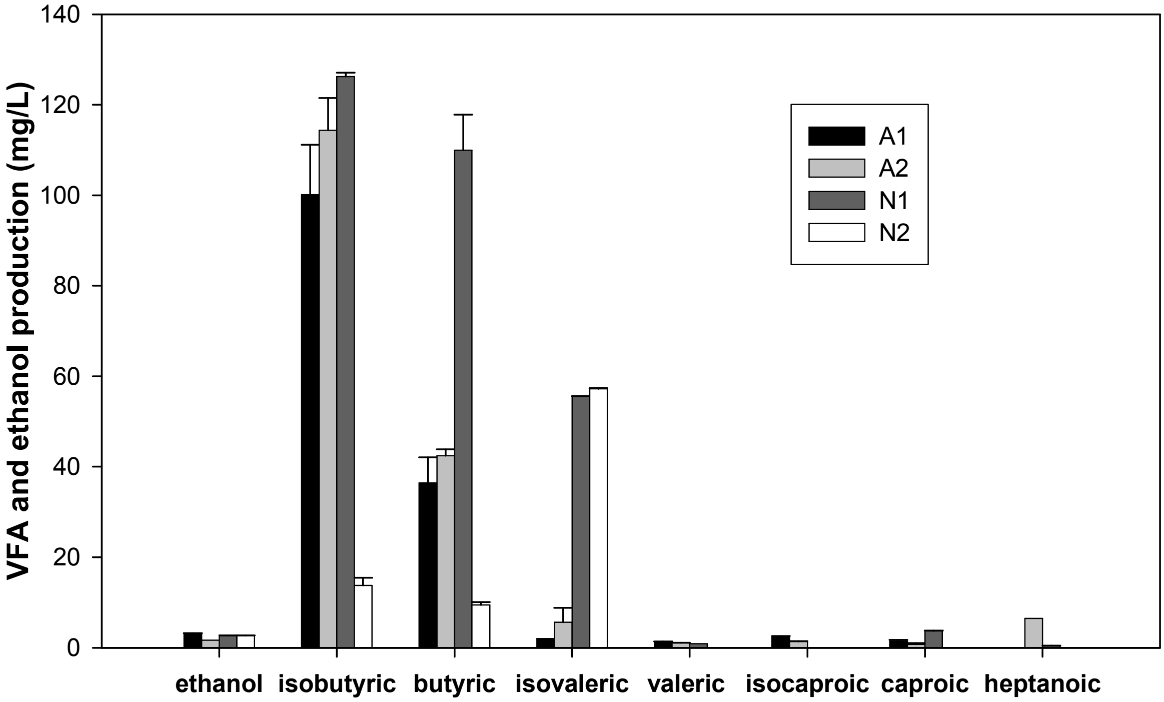

Figure 5 Different VFA productions in the reactors

Besides, propionic acid was not detected in the reactors since it was again utilized immediately by microorganisms due to its simple structure (Speece, 1996). In the study, the concentrations of two organic acids, namely butyric and iso-butyric, were higher than other acids. This was an indication of incomplete degradation of those acids in the reactors. The reason might have been the conversion pathway of these acids as explained in the literature (Han et al., 2005). In other words, the degradation of organic substrate to butyric and iso-butyric acids was achieved first in the reactors; and then a complete conversion of those acids to acetic acid took place. The final step was the production of biogas. However, most probably the conversion of all the butyric and iso-butyric to acetic acid, and then to biogas did not take place in the reactors which led to the existence of those acids at end of the operation period.

4 Conclusions

The results of the BMP experiments revealed that the separation of the anaerobic reactor into two-phase and the application of optimum acidification conditions enhanced the performance of the methane producing reactor in terms of tCOD and VS reductions, and cumulative gas productions for the treatment of organic fraction of municipal solid waste. 10% and 23% increases in tCOD and VS removals were achieved, respectively, by phase separation. The detection of lower tVFA concentrations in the reactors A1 and

A2 was the indication of successful utilization of more acids and in turn more biogas productions. In addition, the lack of acetic and propionic acids was another key indicator for the occurrence of successful methanogenic process in the reactors. As a result, it can be concluded that the phase separation was applicable to improve the performance of the anaerobic systems operated for the treatment of the organic fraction of municipal solid waste.

5 Acknowledgments

This study was funded by The Scientific and Technological Research Council of Turkey through Grant Number 104I127.

6 References

Kühle-Weidemeier, M. (Hrsg.);	2004	Abfallforschungstage 2004. Auf dem Weg in eine nachhaltige Abfallwirtschaft. Cuvillier Verlag, Göttingen, ISBN 3-86537-121-3.
American Public Health Association (APHA);	2005	Standard Methods for the Examination of Water and Wastewater, 21st Edition., Washington D.C
Bhattacharyya, J.K., Kumar S., Devotta S.	2008	Waste Management 2008. Studies on acidification in two-phase biomethanation process of municipal solid waste. 164-169
Demirer G. N. and Chen S.	2005	Process Biochemistry 2005. Two-phase anaerobic digestion of unscreened dairy manure. 40. 3542-549.
Demirer G. N. and Chen S.	2004	Journal of Chemical Technology and. Biotechnolog 2004. Effect of retention time and organic loading rate on anaerobic acidification and biogasification of dairy manure, 79(12) 1381–1387.
Demirer G. N., Duran M., Ergüder T. H., Güven E., Ugurlu Ö.and Tezel U.,	2000	Biodegradation 2000. Anaerobic treatability and biogas production potential studies of different agro-industrial wastewaters in Turkey.11. 401–405.
Dogan E., Dunaev T., Erguder T.H., Demirer G.N.,	2008	Chemosphere 2008. Performance of leaching bed reactor converting the organic fraction of municipal solid waste to organic acids and alcohols. 74. 797-803.

Ghosh, S.	1987	Journal of Environmental Engineering 1987. Improved sludge gasification by two-phase digestion. 113(6). 1265-1284.
S. Ghosh, J. R. Conrad, D.L. Klass	1975	Journal of Water Pollutution and Contol Federation 1975. Anaerobic acidogenesis of sewage sludge. 47(1). 30-45.
Han S., Kim S., Shin H.	2005	Process Biochemistry 2005. UASB treatment of wastewater with VFA and alcohol generated during hydrogen fermentation of food waste. 40.2897–2905.
Viturtia A. Mtz., Mata-Alvarez J., Cecchi F.	1995	Resources Conversion and Recycling 1995. Two-phase anaerobic digestion of fruit and vegetable wastes. 13. 257-267.
Speece R. E.	1996	Anaerobic Biotechnology for Industrial Wastewaters. Archae Press, Nashville, TN.
Prashanth S., Kumar P., Mehrotra I.	2006	Journal of Environmental Engineering 2006Anaerobic Degradability: Effect of Particulate COD. 132 (4). 488-496.
TURKSTAT	2007	TURKSTAT, Turkish Statistical Institute; [cited October 2007] Available from: http://tuik.gov.tr/VeriBilgi.do
Uzal N., Gökçay C. F., Demirer G.N.	2003	Process Biochemistry 2003. Sequential (anaerobic/aerobic) biological treatment of malt whisky wastewater. 279-286.