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Evaluation of the effect of inital solid matter concentration and season on anaerobic biodegradation of municipal solid wastes

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Abstract

The necessity for reduction of fossil fuel consumption and the increasing energy costs drives the interest in development of alternative renewable energies during past years. OFMSW (Organic Fraction of Municipal Solid Wastes) is a valuable source, since it can be converted to biogas via anaerobic digestion. In this study the anaerobic biodegradability and the methane generation potential of the organic fraction of municipal solid wastes (OFMSW) were measured by sampling during three seasons (autumn, winter and summer) of a year and determined using batch bioreactors with varying initial dry solid matter ratios (DM:5-35 %). Batch experiments were carried out both with and without anaerobic inoculum. Biogas production potentials were determined to be in the range of 229 - 484 m^3/ton DM for experiment using anaerobic inoculum and 84 – 176 m^3 /ton DM for experiments without inoculum. The best organic matter combination belongs to autumn season and the best dry matter concentration was observed as 20%

Keywords: biochemical methane potential(BMP); biogas; mesophilic anaerobic degradation; organic fraction of municipal solid wastes (OFMSW)

1. INTRODUCTION

Problems with the burning of fossil fuels had directed the attention to finding sustainable sources for energy production [1]. The energy system plays an important role in sustainability because of its being interlinked with economic development and environmental protection [2]. Waste management has become a major problem worldwide over the past 50 years. Sustainable concepts should be developed to ensure that waste is recycled and that nutrients return to the soil [3]. Many of the environmental problems sourced by solid wastes disposed directly into environment. This could be the reason for odor problems, blocking of waterways and flooding of drains, moreover they can be source of air contamination by natural degradation [4].

OFMSW (Organic Fraction of Municipal Solid Wastes) represents the organic part of all household, community and industrial waste collected by municipalities. The sources of these wastes with high organic content can be produced by human use, agricultural waste or food industry. The waste hierarchy principle has been adopted in OFMSW management and disposal in most developed countries. Studies dealing with application and development of sustainable waste management systems in the world have emphasized recovery of wastes and caveat of removal of sludge toxic substances in addition to offering lower treatment costs [5].

Land filling as a final disposal method has been widely used in many countries. However,

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developed countries don't take into account the method 'land filling' or 'bioreactor with high residence time' as a sustainable final disposal method, since it requires construction and operating of new storage areas for the treatment of liquid and gas emissions, which recovers more than 90% of produced biogas [6-7]. It is very important to develop an integrated solid waste management strategy in terms of public health and environmental protection. The mixing of leachate with drinking water, which may leak to the soil during the decomposition of organic materials at the municipal waste treatment plants, will be a very important problem in terms of public health. Unhealthy applications such as incineration, storage and burial are carried out as the disposal method of organic wastes produced all over the world. Generally organic fraction of municipal solid waste (OFMSW) is a very attractive biomass for biogas plants [8-9]. Aerobic composting or anaerobic digestion are two common treatment methods applied for OFMSW. These technologies are the most important recycling approaches known. The CO_2 emissions caused by aerobic treatment indicate that anaerobic digestion is the most important alternative for sustainable development [10-11]. Anaerobic digestion is known as the natural process in which anarobic bacteria degrade organic matter in oxygen-free environment. Anaerobic technologies are more attractive because of the production of renewable energy in the form of methane [12]. The application of this technology is very common in many european countries [13]. Depending on new developments on anaerobic treatment technologies and legal restrictions that have taken place in regulations of various countries, a new approach that is gaining attention around the world is that energy recovery and material recycle in order to reduce problems deriving from treatment plant waste [7]. There is an increased recognition, in both developing and industrial countries, of the need for resources for technical and economic efficiency. In addition, more widespread use of biogas technology will provide jobs related to the design, operation, and manufacture of energy recovery system [11]. The greatest benefit of OFMSW's energy regeneration is the reduction of gaseous pollutants, both locally and globally, which can cause adverse effects [14]. Energy recovery from organic wastes will greatly contribute to reducing the emissions of water, soil and air pollutants. This approach will also contribute significantly to the fulfillment of Kyoto commitments and sustainable development [15]. Using the clean energy biogas instead of fossil fuels reduces the emission not only of greenhouse gases, but also many hazardous gases [16].

The main objective of this research is to evaluate the effect of solid matter concentration at the beginning and the effect of season on anaerobic digestion of OFMSW and to determine the methane generation potential of organic fraction of municipal solid wastes. Biochemical Methane Potential (BMP) assay was conducted for this purpose with different initial dry matter ratios (ranging between 5 and 35 %). Biochemical Methane Potential Tests (BMP) is a common method known as the first stage of assessment of biogas production from organic waste in batch mode. Thereby it was aimed to determine the maximum tolerable DM that minimizes the required anaerobic bioreactor size. In addition, it was aimed to demonstrate that OFMSW could be a good resource to be used a biofuel for public transportation, which would significantly decrease CO_2 emissions.

2. MATERIAL AND METHODS

2.1. Characterization of Organic Fraction of Municipal Solid Waste

The organic fraction of municipal solid waste (OFMSW) used in BMP assays was provided from Uzundere (Izmir, Turkey) waste management company and was dried at 50°C, shredded after the organic fraction separated and stored at 4°C until used. The three selected temperatures (winter, autumn and summer) in this study were determined depending on seasonal changes in vegetable fruit production and human consumption habits. Since the vegetable-fruit content of the aegean region, where temperate climate prevails, has not changed in the spring and summer months, the spring month has not been examined separately. Some characteristics of Izmir Municipal Solid Waste are shown in Table 1.

Table1. Characterization of Izmir municipal solid waste

Components (ppm)	Average Value *
Moisture (%)	53.4
Organic Matter (%)	36
TOC	119200
N (Total)	4900
C/N	24
pH	7.7
Cr (Total)	208
Cu (Total)	138
Ni (Total)	4
Pb (Total)	64
Zn (Total)	180

** in mg/L except for pH, moisture and organic matter*

2.2. Biochemical Methane Potential (BMP) Experiments

In order to compare the anaerobic degradability capacities of OFMSW, BMP tests were performed in 100 mL dark colored serum bottles. These reactors, which were considered as batch reactors, were closed with rubber stoppers and sealed with aluminum rings to prevent gas escape [17]. The liquid volume in the serum bottle was 50 mL. The OFMSW is kept at a dry solids content of 5–35 % DM. Necessary amount of water was added prior to dry matter concentration. 35% dry matter is added as a demonstration of a system with no water addition and the decrease amounts as 20%, 10% and 5% were tested for tolerable dry matter amount. The serum bottles seeded with granular anaerobic biomass obtained from a full scale anaerobic bioreactor operating on wastewater from beer production effluent. OFMSW was added in varying volumes to meet initial COD concentrations designed in the experimental setup in the BMP reactors, then the headspace was washed with 25% CO_2 - 75% N_2 gas mixture to provide anaerobic conditions. BMP reactors were subjected to anaerobic degradation at 36 ± 2°C in a temperature controlled room. Gas measurement in the reactors is measured daily by water-shift gas meters until the measurement results reach the plateau. In all experiments a control group without organic substrate was used. The results were prepared by taking the average of 3 bottles. The biogas produced on the reactor was removed by glass syringe and injected into a sealed bottle containing 20 g/L KOH. After the bottle was shaken for a while, the reaction of CO_2 with KOH was completed and the remaining gas was removed with a glass syringe to calculate the difference and the percentage of methane. Some results have been confirmed by Gas Chromatography with thermal conductivity detector.

2.3. Basal Medium (BM) and Nutrients

The trace element concentration of the basal medium required for the continuation of minimum vital activities in BMP reactors is prepared according to Azbar et al [17].

3. RESULTS AND DISCUSSIONS

In this study, BMP tests were conducted to investigate the maximum amount of tolerable dry matter content by the mixed consortium in the anaerobic digestion process of OFMSW and the biogas production potential of OFMSW in the city of Izmir . The waste treatment plant was sampled three times to represent the autumn, winter and summer season. The cumulative gas production values obtained from the BMP reactors are shown in Figures 1 to 3. The values in the graphs are prepared by taking the average of the three values. It can be seen that the duration of the acclimation period for anaerobic consortium is 2-3 days. Acclimation perios for all bioreactors are increased by increasing the initial residue concentrations because the hydrolysis stage is getting longer by increasing amount of solid materials. The cumulative biogas production from municipal solid wastes taken in the autumn is a maximum of 200 mL for 35% dry matter content of OFMSW. By decreasing the dry matter content to 20 %; 10 %; and 5 % the biogas production had also respectively decreased to 181 mL; 135 mL and 75 mL respectively (Figure 1).

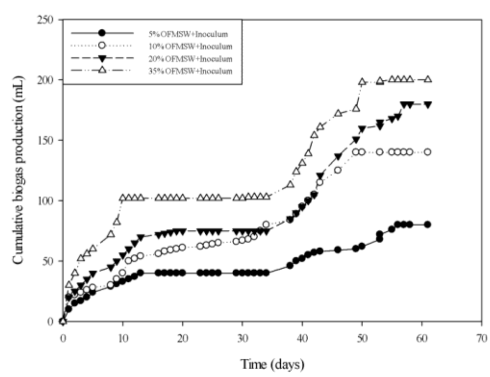

Figure. 1. Cumulative biogas production with anaerobic inoculum in autumn season

After 50 days of operation of OFMSW taken during the winter and the maximum 400 mL gas production is achieved with 20% dry matter content. All cumulative biogas production values are much lower compared with other two seasons. This is likely due to ash content of organic waste in this season (Figure 2).

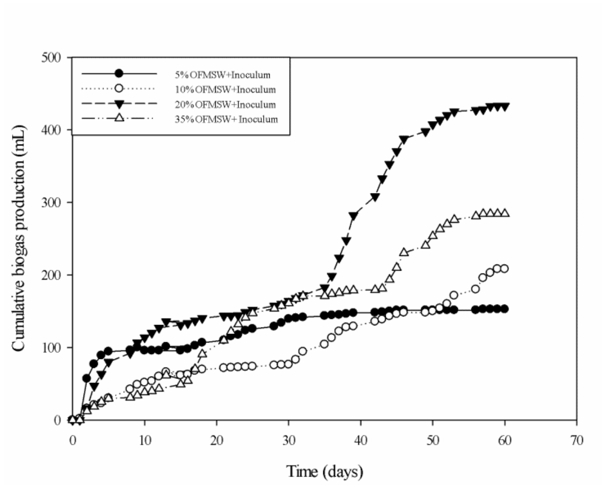

Figure 2. Cumulative biogas production with anaerobic inoculum in winter season

The OFMSW taken during the summer had given the best results in terms of cumulative gas production for all dry matter content trials. Increasing the amount of dry matter resulted in an increased amount of cumulative gas production after 50 days of operation. For 35 %; 20 %; 10 % and 5% dry matter contents 500 mL; 480 mL, 350 mL and 300 mL cumulative biogas production values were obtained respectively (Figure 3).

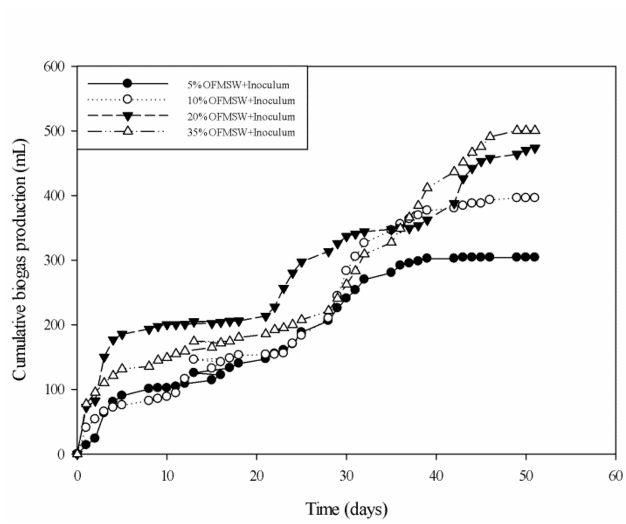

Figure. 3. Cumulative biogas production with anaerobic inoculum in summer season

The same experiments were repeated by adding only 5-35% dry matter solutions (in the absence of anaerobic biomass) and BM to the serum bottles. During the autumn and summer, the highest level of biogas productions are 250 mL and 120 mL with the percentage of dry matter 35%. In winter, the highest biogas production is 36 mL with the percentage of dry matter being 20%. As seen in each of the figures, all the samples of OFSMW samples that were tested resulted in biphasic curves of biogas production. Biogas production started after 7-10 days acclimatization time, then increased to 5th week and a second lag time was observed at 6th week. As the amount of dry matter increased, the amount of cumulative gas production also increased. Figures 4, 5 and 6 show the biogas production as function of varying COD concentrations (3, 10, 30 g/L, respectively) in the bioreactors.

The consumption habits in Izmir changes with the seasons depending on the vegetables and fruits available. Thus the disposed wastes changes and the quality of wastes is affected. For the experiments carried out in three different seasons namely autumn, winter and summer, municipal solid wastes are taken from the waste treatment plant. The effects of seasonal changes of the degradable organic matter in OFMSW was monitored. COD concentrations of 3, 10 and 30 g/L were increased in the serum bottles, as the amount of cumulative gas production had also increased (Figure 4).

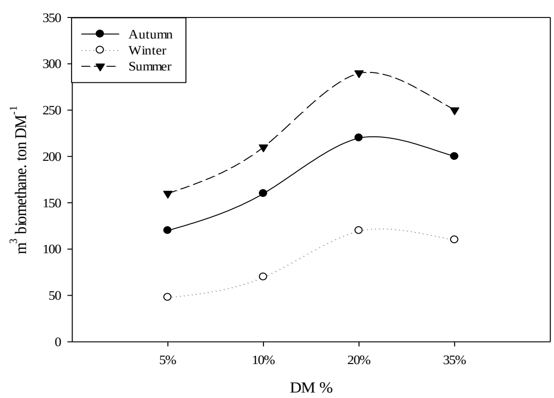

Figure 4. Biogas production as a function of various COD concentrations (3 g/L)

The biogas produced at the end of the study at day 50, in the serum bottles with COD concentrations of 3, 10 and 30 g/L were measured to be 296, 451, 509 mL with the percentage of dry matter 20% in summer (Figure 5).

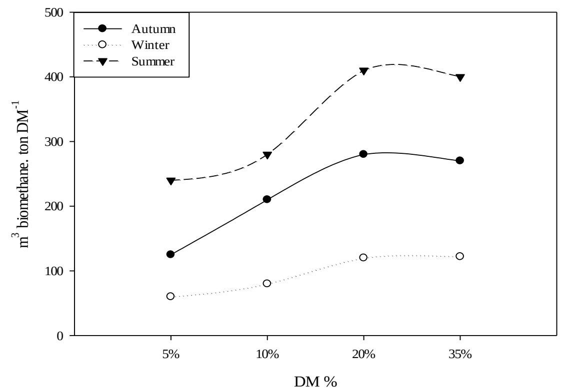

Figure.5. Biogas production as a function of various COD concentrations (10 g/L)

The cumulative biogas production of BMP reactors were increased with increasing dry matter amount from 5% up to 20%. For the highest dry matter of 35%, biogas production seemed to slow down (Figure 6).

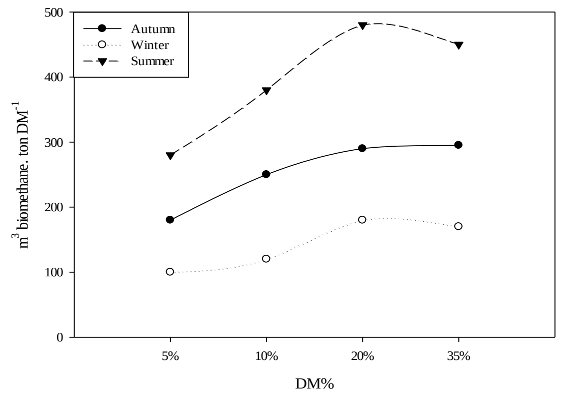

Figure 6. Biogas production as a function of various COD concentrations (30 g/L)

By comparing the results achieved with as well as without the addition of inoculum addition and with inoculum addition, one can observe that OFMSW is a good source of biogas production. OFMSW can be improved by adding necessary anaerobic consortium-especially methanogens-by using that necessary microorganisms that are involved in anaerobic stages like hydrolysis, acidification and methanogenesis but it can be improved by adding necessary anaerobic consortium especially methanogens.

Upon comparing the results in Fig 1-3 the positive effect of inoculum addition on biogas production is clearly seen. In an anaerobic bioreactor, the hydrolysis stage of municipal solid waste municipal solid wastes generally take about at least 15 days.

Xu et al. [8] had conducted an artificial neural network study in order to compare the performances of biogas production 10 different types of lignoselulosic waste cited on 10 different research papers. The main idea is that lignocellulosic waste can be a good source for biogas production, and whereby an upwards 150 m^3CH_4/ton biomass can be produced. The acclimation time in order to complete the hydrolysis step is too long and an average value of 28 days was observed. As can be seen in Fig 1-3 as well as 4-6, 15-22 days of lag phase is observed for different seasons and different dry solid contents.

Nyugan et al. [7] had suggested a design to avoid the lag time being consumed. They had studied on bioreactor of two rounds. During the first run the hydrolysis step was enhanced by microaertion and during the second run only methanogenesis had occured so 75% biogas conversion was observed. The lag time was observed as 30 days and the total amount of biogas production was 260 m^3CH_4/ton waste.

The environmental temperatures presented in this study ranged between 0-2 ºC during the winter, 20-22 ºC during the autumn and 35-40 ºC during summer. These three seasons were chosen for the experiment allowing the range of external temperatures to be considered. The temperature directly effects the growth of vegetables, fruits etc.

Cechi et al. [18] studied on the seasonal effect of anaerobic digestion of the source sorted organic fraction of municipal solid waste. They had examined the effect of temperature on the reactor performance and however their study does not include seasonal influence the waste quality. They had found a doubled specific gas production rate and thus in better stabilization of the sludge digested. As it can be seen in Fig. 1 to 3 for all organic matter concentration values doubled gas production is was observed in the summer for all organic matter concentrations. The reactor temperature was kept constant at 35±2 ° C thus meaning that the improvement in gas production capacity is sourced by quality of biodegradable portion of the waste.

Forster-Carniera et al. [19] had also studied on biogas production from the organic fraction of municipal solid waste in lab scale reactors. 5L reactor were used to compare the performances of organic fraction of municipal solid waste and municipal solid wastes without screening for organic content. The lag time was 10 days longer than OFMSW reactors and the total biogas production values were 25 m^3CH_4/ton MSW and 120 m^3 CH_4/ton OFMSW. The wastes were collected from the university caffetaria and however the seasonal effect was not tested. In our study similar results were obtained for the winter season.

The effect of initial substrate concentration of OFMSW was also tested in lab scale reactors [20]. The biogas production potential under mesophilic conditions were compared at two different initial dissolved material content (of 20% and 30 %). Higher biogas production values were observed by 30% dry matter content and the CH_4 production values were 279-411 m^3 CH_4/ ton of OFMSW. The dry matter contents were similar as this study and the total amount of produced gas are lower with summer season results. The lag time reported was 49 days for 30% dry matter content but in our study the maximum lag time was 22 days which is an advantage for large scale applications.

Getahun et al. [21] had studied the biogas production potential of municipal solid waste in tropical environments. Municipal solid waste were screened as being fruit wastes, paper wastes, yard wastes and mixed wastes. The biogas production potentials were tested for dry matter amounts of 4-20%. The highest biogas production values were reported as being 148 m^3/ton of fruit and vegetable waste. The main part of a municipal solid waste is fruit and vegetable wastes and it was reported that using just fruit and vegetable waste carries the main advantage of a having a very short lag time as 5 days. Thus it can be understood that the composition directly affects the biogas production yields.

In our study the components of OFMSW differs greatly in different seasons and the organic fraction other than fruit end vegetables increased slightly in terms of lag time.

Another study by Ashik and Mohan. [22] aimed to test the effect of dry matter contenton biogas production from municipal solid waste. For this purpose lab scale reactors were used and the dry matter content was changed as 10%, 20 % and 30% which is the same amounts with our study. The biogas production values were changed from 214-383 m^3 CH_4/ ton MSW. The wastes were collected during autumn season. In our study the values were higher than this total production values because by using the organic fraction of municipal solid wastes we have eliminated the inhibitory effects of toxic materials which are hard to degrade in municipal solid wastes.

Kigozi et al [23] and Curry and Pillay [24] had studied on biogas production from OFMSW with mesophilic systems. Again their studies resulted in between 300-400 m^3 CH_4/ton biomass biogas production. All of these results in comparison with our study are listed in Table 2.

Co-digestion processes are generally used for improving the anaerobic biodegradability of municipal solid waste. Rintala et al. [25] had applied the co-digestion of OFMSW with sewage sludge and achieved 300 m^3 CH_4/ton OFMSW; Hartman and Ahring [3] co digested OFMSW with manure at thermophilic conditions and achieved 180-220 m^3 biogas/ton OFMSW; Gomez et al. [9] studied on digestion of primary sludge and co-digestion of sludge with the fruit and vegetable fractions of municipal solid wastes. After biogas production operation they achieved 200-300 m^3 biogas/ton OFMSW. Zhang et al. [26] was studied on investigation of methane fermentation of sewage sludge and organic fraction of municipal solid wastes and achieved 400-600 m^3 biogas/ton OFMSW.

In our study for the OFMSW taken in summer total biogas productivity values achieved like 425-500 m^3 biogas/ton OFMSW without co-digestion at mesophilic conditions. But regarding the autumn and winter trials co-digestion with a more biodegradable waste could produce high biogas.

Table 2. Comparison of biogas production potentials of OFMSW and MSW

Waste	Reactor	Lag Time	Co-digestion	Methane Production m^3 CH_4/ton biomas	Ref.
OFMSW Manure	Batch	-	Yes	180-200	[3]
OFMSW Primary Sludge	Batch	-	Yes	200-300	[9]
OFMSW	Batch	10	No	25-120	[19]
OFMSW	Batch	22	No	279-411	[20]
MSW	Batch	5	No	148	[21]
OFMSW	Batch	15	No	214-383	[22]
OFMSW	Batch	11	No	400	[23]
OFMSW	Batch	20	No	300	[24]
OFMSW Sewage Sludge	Batch	-	Yes	180-200	[25]
OFMSW Sewage sludge	Batch	-	Yes	400-600	[26]
OFMSW	Batch	-	No	425-500	**This study**

These gains are in the form of; reduced greenhouse gas emissions, acid gas emissions, depletion of natural resources (fossil fuels and materials) and impact on water (leaching), land contamination. Deployment of MSW energy recovery should be encouraged wherever it presents a viable and attractive way of integrating with recycling and re-use activities and minimizing the impact of waste disposal.

The rate and extent of biogas production depends on the amount of dry matter and the microorganisms involved. A noticable increase in the amount and the rate of gas production was observed when dry matter, trace metals and nutrients were supplemented. The function of this process is to reduce the volume and weight of OFMSW, stabilize the waste and after anaerobic digestion using the waste as compost which is rich in inorganic nutrients. Even though, this was a preliminary study, a promising amount of biogas was produced which can be used as a renewable energy source.

CONCLUSIONS

In summary, OFMSW is a highly biodegradable waste. Biological degradability of OFMSW and biogas production are highly influenced by seasonal compositions.An enhancement in the amount of the biogas production was observed. In comparison to some common disposal methods of OFMSW, such as combusting and land filling, the management of OFMSW using anaerobic degradation in bioreactors could be proposed as an economically viable and ecologically acceptable solution, because it provides both a safe disposal of OFMSW and renewable bio-fuel that could be used in public transportation. Organic fraction of municipal solid wastes are very effective substrates for biogas production.-Seasonal changes directly effects the organic content and the biogas production capacities. Amongst different dry matter content values 20% concentration gives the best results in terms of biomethane production.

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