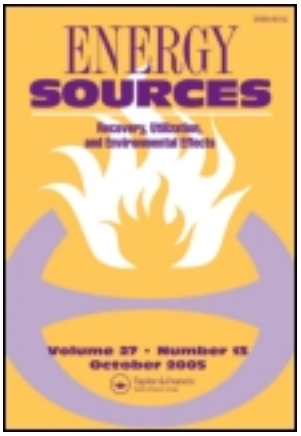
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Methane Production from Plant Wastes and Chicken Manure at Different Working Conditions of a One-stage Anaerobic Digester

O. Yaldiz [a], S. Sozer [b], N. Caglayan [a], C. Ertekin [a] & D. Kaya [c]
[a] Department of Farm Machinery, Faculty of Agricultural Engineering, Akdeniz University, Antalya, Turkey
[b] TKB, Aksu Tarim Ilce Mudurlugu, Aksu, Antalya, Turkey
[c] TUBITAK MAM, Gebze, Kocaeli, Turkey

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Methane Production from Plant Wastes and Chicken Manure at Different Working Conditions of a One-stage Anaerobic Digester

O. YALDIZ,[1] S. SOZER,[2] N. CAGLAYAN,[1] C. ERTEKIN,[1] and D. KAYA[3]

[1]Department of Farm Machinery, Faculty of Agricultural Engineering, Akdeniz University, Antalya, Turkey
[2]TKB, Aksu Tarim Ilce Mudurlugu, Aksu, Antalya, Turkey
[3]TUBITAK MAM, Gebze, Kocaeli, Turkey

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Abstract *This article presents laboratory scale studies on the anaerobic digestion of plant wastes using a continuously flow type vertical cylindrical biogas plant. In the first experiment, plant wastes and chicken manure mixture at a dry matter content of 12%, retention time of 30 days, and fermentation temperature of 35°C were examined (Exp. 1). In the second experiment, fermentation material was grass and grass silage, covered marketplace wastes, rumen waste, chicken manure, and cattle manure. The experiments were conducted at a dry matter content of 9%, retention time of 47 days, and fermentation temperature of 35°C (Exp. 2). According to the results, biogas production was 1,055.7 l per day in Exp. 1 and 721.4 l per day in Exp. 2. The raw material specific biogas production was 0.310 l per g of organic dry matter per day in Exp. 1 and 0.443 l per g of organic dry matter per day in Exp. 2. The reactor specific biogas production was 1.05 l per l per day in Exp. 1 and 0.72 l per l per day in Exp. 2. Reactor specific methane production was 0.425 l per l per day in Exp. 1 and 0.381 l per l per day in Exp. 2. Raw material specific methane production was 0.125 l per g of organic dry matter per day in Exp. 1 and 0.234 l per g of organic dry matter per day in Exp. 2. The material pH value was 5.59 and 6.15 for inlet and 7.97 and 8.19 for outlet for Exp. 1 and Exp. 2, respectively. The methane content ranged between 40.3 and 52.9%.*

Keywords anaerobic fermentation, biogas, plant wastes

Introduction

An increasing world population and spreading of high technology products increases the energy consumption per capita, so the energy production in the world should be improved necessarily. The total world primary energy consumption was 138,431.1 billion kWh in 2006 and it will reach 203,616.6 billion kWh by 2030 with an annual rate of 1.6%. The net electricity consumption was 16,378.6 billion kWh in 2006 over the world and will reach up to 17,292.9 billion kWh in 2030 (IEA, 2009). The share of fossil sources is still high and the share of renewables in the world primary energy production and net electricity generation is 1.6 and 2.3% in 2006, respectively (IEA, 2009). Decreasing fossil

Address correspondence to Dr. Can Ertekin, Department of Farm Machinery, Faculty of Agricultural Engineering, Akdeniz University, Antalya 07070, Turkey. E-mail: ertekin@akdeniz.edu.tr

energy sources reserves, rapid increase in the energy price, pollution prevention targets, and sustainable solutions for handling and recycling of animal manure and organic wastes raises the importance of the renewables all over the world.

One of the renewable energy sources is biogas and its usage technology is growing up by improvements in the biogas engines. The EU countries have agreed on supporting the production of biogas as a renewable energy source in combined heat and power plants in order to decrease the greenhouse gas emissions according to the Kyoto protocol (CEC, 2001). Through Directive 2003/30/EC, the European Commission has obliged all member states to develop and implement policies to promote the use of bio-fuels in the transport sector. Goals are set at 2% replacement of the transport sector's energy use by bio-fuels by the end of 2005 and 5.75% replacement by the end of 2010. EU member states have the freedom to choose fuels and policy instruments that fit their national situation (Wellinger, 2005). A proposal for new directives with the higher target of 10% bio-fuel substitution by 2020 has recently been announced (EC, 2007). For example, between 600 and 800 buses for municipal transportation were bio-methane compatible in Sweden in 2005 (Eriksson and Olsson, 2007).

Food wastes contain high water content, thus, they are suitable for biogas production. These wastes were mostly disposed of by feeding livestock in the past. However, producing biogas from leftover kitchen waste is becoming an ever more important waste disposal alternative as feeding such waste to animals has been prohibited throughout the EU since November 2006 (EC, 2002). Anaerobic digestion has been traditionally used as a cost-effective and promising technology that provides energy recovery among various treatment methods used for kitchen garbage and excess sludge from a biological sewage treatment process (Lee et al., 2009).

In addition, for enhancing yields during the anaerobic digestion by treating animal wastes, some modifications in mechanical pretreatment, temperature, and mixing mode could be in progress. Nevertheless, because of the high organic content, high biological oxygen demand and low carbon/nitrogen ratio compared to domestic or vegetable wastes, the enhancement of yields in the anaerobic treatment of the meat industry wastes can be accomplished by anaerobic digestion (Buendia et al., 2009). Kiely (1998) [from Igoni et al., 2008] announced that anaerobic digestion is used worldwide for the treatment of industrial, agricultural, and municipal waste-water and sludge. Biogas production in the EU-27 continued to rise over the last few years and totaled 62 TWh in 2006 (DENA, 2009). A number of full-scale anaerobic digesters for biogas production have been developed in Denmark and Sweden and have been in operation for the last 20 years. In addition, there were about 3 million small scale biogas plants, operating generally under mesophilic conditions, which had been built in India (Alvarez and Liden, 2009). Up to the end of 2005, China has 17 million digesters with an annual production of 6.5 billion m^3 biogas, mostly in rural areas, with 50 million people enjoying the benefits of biogas technology (Kangmin, 2006). Electricity production from biogas grew from an estimated 5,000 GWh in 1990 to 13,617 GWh in 2001 in the USA. The largest proportion of biogas electricity (58.1%) is in OECD-Europe (Zheng et al., 2009). In Germany, over 3,700 agricultural biogas plants were in operation, producing a total capacity of 1,270 MW of electricity by the end of 2007. Only in 2007, 22.4 billion kWh of biogas were produced, 49% of which was produced from landfill and sewage gas and 51% from commercial and agricultural biogas plants (DENA, 2009).

In the absence of oxygen, anaerobic bacteria ferment biodegradable matter into methane and carbon dioxide and this mixture is called biogas. The gas is colorless, relatively odorless, and flammable, it is also stable and non-toxic (Igoni et al., 2008).

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Biogas contains 60–70% methane and 30–40% carbon dioxide depending on the fermented material. Trace amounts of hydrogen sulfide, ammonia, hydrogen, nitrogen, carbon monoxide, oxygen, and siloxanes are occasionally present in the biogas (Jingura and Matengaifa, 2009). It also has an energy value of 21 MJ (Murphy and Power, 2009).

Digestion can take place at either mesophilic (35–40°C) or thermophilic (55–60°C) temperature ranges. Mesophilic digestion tends to be more robust and tolerant than the thermophilic process, but gas production is less and larger digestion tanks are required. Higher methane production causes faster through output, better pathogen and virus kill, but has a more expensive technology, with a greater energy input, and a higher degree of operation and monitoring (Singh and Prerna, 2009).

Interest in the anaerobic treatment of agro-industry waste is increasing because it is economical, has lower energy requirements, and is ecologically sound, among several other advantages, compared with aerobic treatment processes. At the end of anaerobic fermentation, sludge could be used as fertilizer for crop production since the nutrients in the raw material remain in the mineralized sludge as accessible compounds and the content of pollutants is also low. Treating waste to yield while recycling nutrients constitutes a sustainable cycle (Singh and Prerna, 2009; Bouallagui et al., 2009).

In this study, the usage possibilities of plant wastes in anaerobic fermentation process was examined. The biogas production, raw material specific biogas production, digester specific biogas production, digester specific methane production, raw material specific methane production, pH values of the material, and gas content of the biogas were evaluated.

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Material and Methods

This study was conducted in Akdeniz University, Faculty of Agriculture, Department of Farm Machinery, Antalya, Turkey with a continuous flow-type vertical cylindrical laboratory biogas plant having a fermentation volume of 1,000 liters.

The first experiment was done with the composition of plant wastes at 50% and chicken manure at 50% with a dry matter content of 12%, retention time of 30 days, and fermentation temperature of 35°C. The plant wastes consist of carrot, cabbage, leek, lettuce, parsley, onion, potatoes, and cucumber with a rate of 17.8, 30.3, 24.4, 13.3, 2.2, 2.7, 5.9, and 3.4%, respectively (Exp. 1). The daily loading rate was 4,000 g of dry matter and 3,400 g of organic dry matter. The plant wastes were taken from the university central cafeteria during the preparation of meals. They were used after the preparation process for fermentation by the material conditioning unit. The plant wastes were then stored in cold storage rooms until the experiments.

In the second experiment, working conditions were arranged as dry matter content of 9%, retention time of 47 days, and fermentation temperature of 35°C. The fermentation material was grass and grass silage, covered marketplace wastes, rumen waste, chicken manure, and cattle manure with a rate of 57.62, 18.17, 3.81, 17.29, and 3.1%, respectively (Exp. 2). The daily loading rate was 1,914 g of dry matter and 1,626.9 g of organic dry matter.

Experimental Unit

The experiments were conducted in a continuous flow-type vertical cylindrical laboratory biogas plant having a total volume of 1.2 m^3 and a fermentation volume of 1 m^3. This experimental unit consists of a digester, material preparation unit, and control panel.

The Digester

The digester consists of two cylinders intertwined with each other. The inner cylinder works as a fermentation chamber and has the second cylinder outside of it by 50 mm. Water is added between these two cylinders and the fermentation temperature is adjusted by the temperature of this water. This water is heated by four resistances to reach the desired temperature, and its temperature was measured by thermocouples at two different digital thermostats, each controlling two resistances. All the design materials were made of stainless steel to prevent corrosion. In order to reduce heat losses from the digester, it was covered with glass wool and also metal sheet. There is a loading and unloading channel in the digester. The loading channel is connected to the mud pump inside the material preparation unit. The unloading channel is used to remove the fermented material outside the system by a small carrier. Also, there is another channel at the underside of the digester to remove all the material for the cleaning process at any time.

There are two different mixers in the fermentation chamber to achieve effective mixing. The first is a finger type, connected to the top side, which rotates at 30 min^{-1} and works with 0.75 kW power. The other is a mixer type, connected to the side wall of the fermentation chamber, and its rotation could be changed by a cycle changer on the control panel as requested (with a maximum of 400 min^{-1}) working with 0.75 kW power.

Material Preparation Unit

The dimensions of raw materials were reduced by pre-processing using a material conditioning unit consisting of two different cutting devices, a spiral minced meat cutting machine and an industrial rubbish grinding machine. With the former, it is possible to obtain different material sizes by using different opening sizes during the cutting processes. In the other one, the loaded material is cut into small pieces by a high rotating knife. So, this unit makes it possible to grind different plant materials, such as fibrous or very soft materials containing a high level of water.

A mixing tank of plant materials was used by adding the required water. These mixed plant wastes were loaded to the fermentation chamber by a mud pump. The working time of this pump could be arranged, so the loaded material amount could be adjusted at control panel.

Control Panel

The control panel consists of a PLC monitor, two digital thermostats controlling the heaters, and an emergency stop button. The fermentation temperature, rotating speed, and time of mixers could be arranged on the PLC monitor.

Method

Experiments

In order to increase methane bacteria population and improve methane gas production before the experiments, the digester was loaded with cattle manure with a volume of 1/3. Then the digester was loaded by mentioned wastes for Exp. 1 and Exp. 2.

The experiments were conducted at two different dry matter contents of 9 and 12%, a fermentation temperature of 35°C, and retention times of 30 and 47 days for different fermentation materials.

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Collecting Data

The data were taken at the same time every day regularly and the loading process was verified. The biogas amount, biogas content, pH values, dry matter, and organic matter contents of loaded and unloaded material were examined daily.

The produced biogas passed through the pressure valve by a pipe from the up side of the digester and then entered to the flowmeter. The total gas amount was read from the flowmeter every day at the same time.

The gas content of the biogas, methane, carbon dioxide, oxygen, and hydrogen sulfur, were examined by a gas analyzer (Ados brand). The loaded and unloaded material pH values were regularly measured by digital pH meter (WTW brand). Three samples were taken while loading the material into the digester to determine dry matter content in an oven at 105°C for 24 h (APHA, 1995). The weighing process was done by digital balance with an accuracy of 1%. The organic dry matter content was determined by an ash oven at 550°C for at least 4 h (Nuve brand) (APHA, 1995).

Results and Discussions

According to the results, while the biogas production was 1,055.7 l per day with a standard deviation of 270.6 l per day in Exp. 1, it was 721.4 l per day with a standard deviation of 166.3 l per day in Exp. 2. In another study, co-fermentation of cattle manure and sugarbeat at a retention time of 2 days, fermentation temperature of 55°C, the biogas production were changed between 22.5 and 24.6 l per day, which is higher than the experiments done by only cattle manure (17.5 l per day) (Umatsu et al., 2006).

It is clear from Figure 1 that the gas production is higher for Exp. 1 and the daily differences were also higher. The gas production is lower in Exp. 2 because of the sawdust in the chicken manure used in this experiment. In one study, done with cattle manure and sawdust to examine the effect of sawdust in biogas production, the methane production decreased because of the stress in the fermentation process if the sawdust rate was over 40% at a fermentation temperature of 35°C and over 70% at 55°C (Hashimoto, 1983). The loading of plant wastes over the evident rate decreases the methane production.

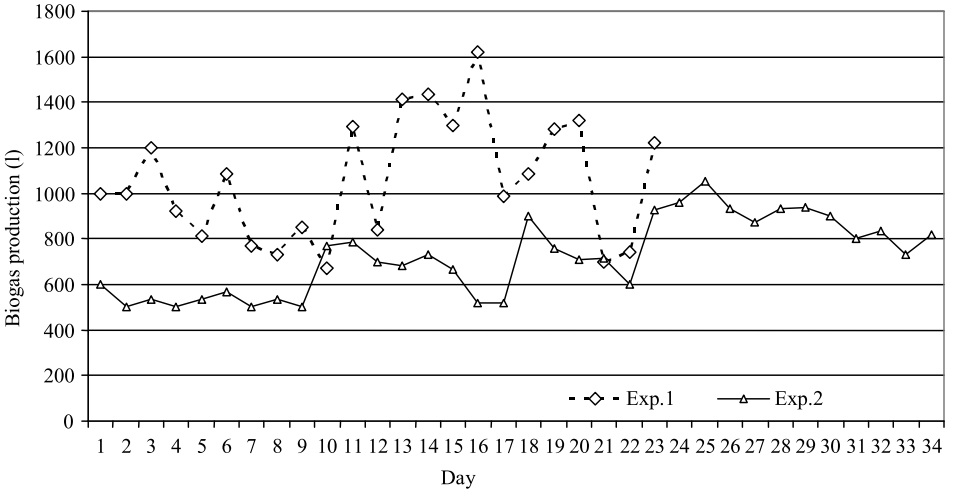


Figure 1. Daily biogas production.

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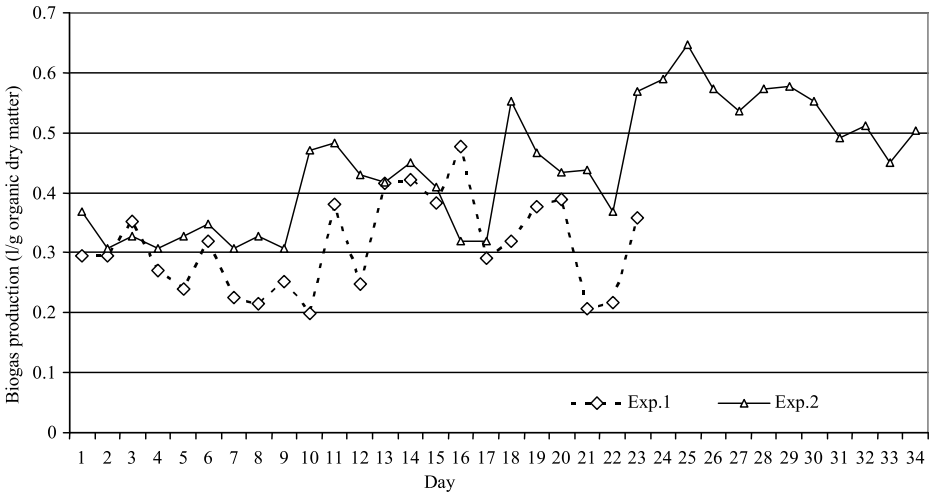


Figure 2. Raw material specific biogas production.

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In order to determinate and evaluate reaction conditions and raw material gas productivity, the produced gas amount per loaded unit weight organic dry matter is an important parameter. While an increase in loaded organic dry matter caused an increase in total gas production, the benefit rate from dry matter decreases. This is the result of the low level of the bacteria population. In spite of this, high organic dry matter rates are generally preferred because of high total gas production. The raw material specific biogas production was 0.310 l per g of organic dry matter per day for Exp. 1 and 0.443 l per g of organic dry matter per day for Exp. 2 (Figure 2).

Although the biogas production was higher in Exp. 1, the raw material specific gas production was lower than Exp. 2 as a result of the lower loading rate. This rate was changed between 0.38 and 0.47 l per g of organic dry matter per day for fermentation of rice stalks at a fermentation temperature of 35°C and retention time of 24 days according to the applied pre-processes (Zhang and Zhang, 1999). Stroot et al. (2001) reported that the raw material specific biogas production changed between 0.17 and 0.47 l biogas per g of organic dry matter per day in fermentation of house solid wastes, first sludge and active sludge mixings at retention times of 3.9–20.3 days and loading rates of 5.5 g of organic dry matter per l per day. The maximum raw material specific biogas production for pineapple shells at a fermentation temperature of 30°C was found to be 0.52 l of biogas per g of organic dry matter per day at the constant loading rate of 60 g of organic dry matter per l per day and retention time of 30 days and as 0.63 l biogas per g of organic dry matter per day at the constant loading rate of 60 g of organic dry matter per l per day and retention time of 25 days. So, at the same conditions it is not possible to improve raw material specific biogas production by increasing the loading rate or retention time, optimum conditions should be determined (Rani and Nand, 2004). Madhuraka et al. (1997) reported that the raw material specific biogas production was found to be 0.65 l per g of organic dry matter per day for stored pea shells at a dry matter content of 6% and retention time of 25 days. Kalia et al. (2000) examined that, while working the fermentation of banana body wastes, the reduction of retention time caused a decrease in biogas and methane production at low loading rates (<4% dry matter) but

this production increased with a reduction of retention time at higher dry matter contents (>8% dry matter).

The reactor specific biogas production is defined as the biogas production per unit reactor volume per unit time. An increase in this value supplies more benefit from unit reactor volume and, thus, the biogas plants could be built in lower volumes more economically. The reactor specific biogas production was 1.05 l biogas per l reactor volume per day in Exp. 1 and 0.72 l biogas per l reactor per day in Exp. 2 (Figure 3). The high dry matter content increases the gas production and also decreases the digester volume. In addition to the increase in dry matter content, a decrease in retention time causes a decrease in raw material specific methane production (Yaldiz, 1987). The maximum reactor specific biogas production for olive pulp at a fermentation temperature of 37°C was obtained as 0.47 l biogas per l reactor volume per day at the loading rate of 10% dry matter (Dalgic, 1998).

Reactor specific methane production is defined as methane production from the unit reactor volume per unit time and is more meaningful in energy production calculations than the biogas production. Because it is not possible to calculate energy production of the plant by using only biogas production, this calculation is generally made by using the methane amount in the biogas because of its flammability. In this study, reactor specific methane production was higher in Exp. 1 with 0.425 l CH_4 per l reactor volume per day. This value was 0.381 l CH_4 per l reactor volume per day in Exp. 2 (Figure 4). The retention time is one of the effective factors on methane production in biogas fermentation. Extention of retention time causes a decrease in reactor specific methane production (Yaldiz, 1996). Decreasing retention time from 25 days to 10 days for fermentation of cattle manure at a temperature of 35°C resulted in an increase of reactor specific methane production of about 73% (Gosch, 1984). The maximum reactor specific methane production was 1.674 l CH_4 per l reactor volume per day at a dry matter content of 8% retention time for 15 days for fruit and vegetable wastes at a fermentation temperature of 35°C (Bouallagui et al., 2003). Tekin and Dalgic (2000) obtained maximum reactor specific methane production at a fermentation temperature of 37°C, dry matter content of 10%, and retention time of 20 days as 0.55 l CH_4 per l reactor volume per day from

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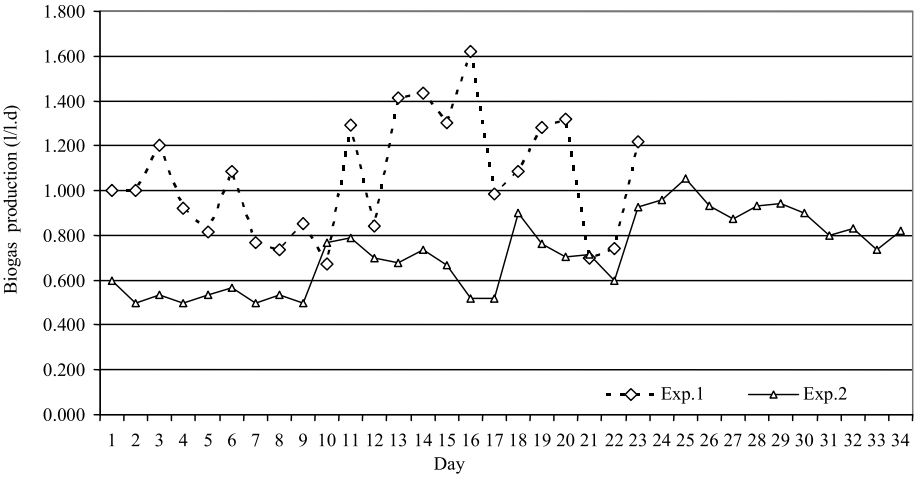


Figure 3. Reactor specific biogas production.

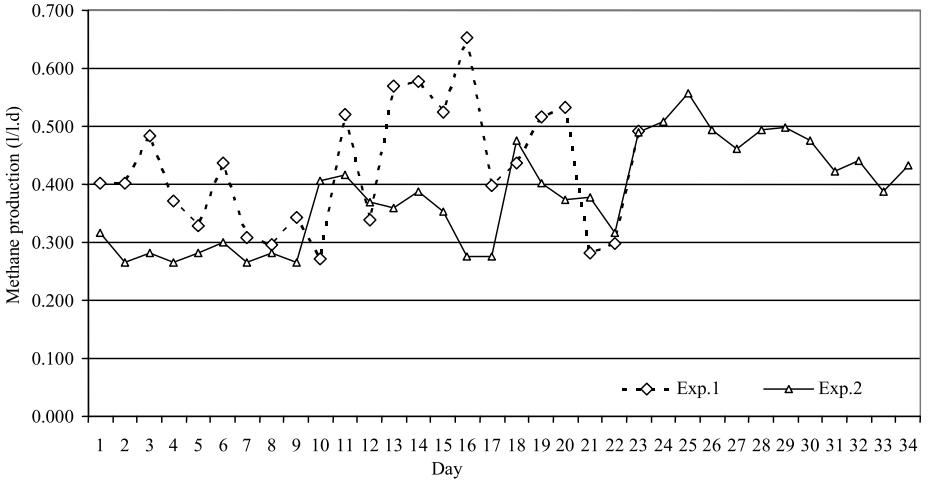


Figure 4. Reactor specific methane production.

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olive pulp. This value was between 0.10 and 0.30 l CH_4 per l reactor volume per day for brown trout farm wastes at fermentation a temperature of 24–25°C (Lanari and Franci, 1998). The maximum reactor specific methane production for fermentation of sugar beet head, wheat straw, and silage fodder wastes was 5.4 l CH_4 per l reactor volume per day at a fermentation temperature of 35–37°C (Andersson and Björnsson, 2002). In bio-wastes, the reactor specific methane productions were ranged between 2.5–6.1 per l reactor volume per day in different studies (Cecchi et al., 1996; Mata-Alvarez et al., 1993; Vallani et al., 1993; Pavan et al., 2000; Scherer et al., 2000).

Raw material specific methane production is defined as the methane amount produced by loaded unit weight organic dry matter per unit time. An increase in the loaded organic dry matter amount at constant fermentation conditions causes a decrease in raw material specific methane production. This result is also obtained in this study. An increase of loading rate at the same retention times caused a decrease in raw material specific methane production. It was 0.125 in Exp. 1 and 0.234 l/g of organic dry matter per day in Exp. 2 (Figure 5). The raw material specific methane production for fermentation of silkworm wastes, poplar leaves, and wood was ranged between 0.130 and 0.374 l CH_4/g dry matter at fermentation temperature of 37°C (Patrabansh and Madan, 2000). Pouech et al. (2000) announced that the methane production changed between 0.295 and 0.409 l CH_4/g of organic dry matter for different plant materials. In addition, this production ranged between 0.384 and 0.627 l CH_4/g of organic dry matter for different vegetation periods of wheat, clover, and grass. Mshandete et al. (2004) found that the raw material specific methane production was 0.32 l CH_4/g of organic dry matter per day for hemp pulp at a retention time of 25 days and 0.39 l CH_4/g of organic dry matter per day for fish wastes at a retention time of 29 days at a fermentation temperature of 27°C. The fermentation of hemp pulp and fish waste mixings at retention time of 24 days resulted in 0.31–0.62 l CH_4/g of organic dry matter per day. Nordberg and Endstrom (1997) reported that the raw material specific methane production was 0.38 l CH_4/g of organic dry matter for minced fodder plant silage, 0.25–0.31 l CH_4/g of organic dry matter for wheat straw, and 0.31 l CH_4/g of organic dry matter for only liquid cattle manure at a fermentation temperature of 35°C, retention time of 9 days, and a loading rate of 6 g of organic dry

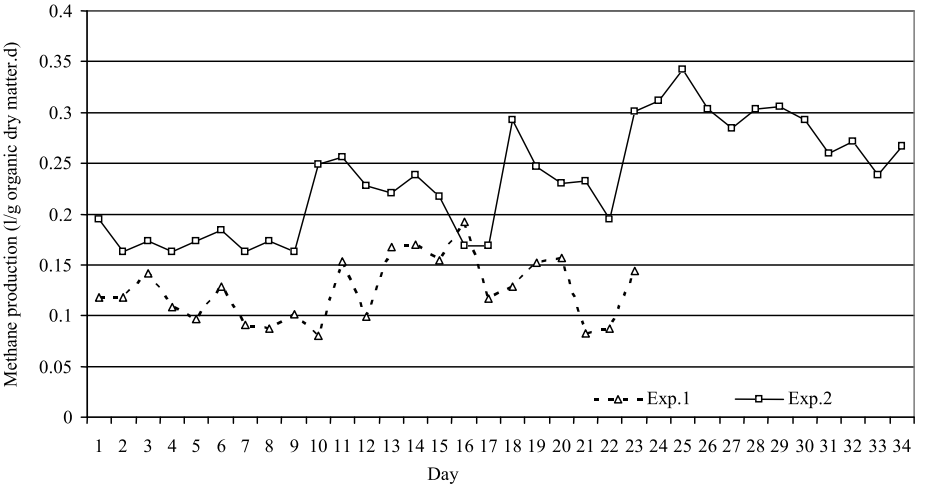


Figure 5. Raw material specific methane production.

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matter per l per day in a batch system. This methane production was changed between 0.125–0.275 l CH_4/g of organic dry matter for fermentation of different tobacco wastes at fermentation temperature of 26.5–33°C, a retention time of 25 days, and a loading rate of 1.5% organic dry matter (Meher et al., 1995). An addition of fruit and vegetable wastes with a rate of 15% on dry matter basis to the cattle, chicken, sheep, and goat manure, "melas" and fermentation sludge at a fermentation temperature of 35°C and a retention time of 34 days, the methane production was ranged between 0.120 and 0.250 l CH_4/g of organic dry matter per day (Misi and Forster, 2001).

The pH values of the experimental material at the inlet was 5.59 in Exp. 1 and 6.15 in Exp. 2. These values showed that the fermentation processed well because they are not too low. Lower inlet pH values generally generate some problems in fermentation. The outlet pH values were 7.97 and 8.19 for Exp. 1 and Exp. 2, respectively. The pH values after the fermentation for biogas production was increased to a suitable range. It was as a result of conversion of acid to the methane. The pH values are generally 7 or over in biogas fermentation except high fermentation temperatures.

The contents of the obtained biogas were shown in Table 1. The methane content was 40.28 and 52.88% for Exp. 1 and Exp. 2, respectively. The methane content was 60% for fermentation of potato wastes (Ross and Walsh, 1996), 68% for active waste sludge, and fruit-vegetable wastes at a fermentation temperature of 30°C (Dinsdale et al., 2000).

Table 1
Content of the biogas

Experiment	CH_4, %	CO_2, %	O_2, %
1	40.28	59.00	0.72
2	52.88	46.50	0.62

The methane content of the biogas changed between 39.8 and 60.8% for eight different plant materials (Chanakya et al., 1999): between 49.4 and 52.1% for rice straw at a retention time of 24 days and a fermentation temperature of 35°C (Zhang and Zhang, 1999); between 48.9 and 57.6% for sea salmon farm wastes at a fermentation temperature of 35°C and a retention time of 24–60 days (Gebauer, 2004); between 60 and 68% for fruit wastes, canalization sludge, and fermented sludge at a retention time of 22.5 and 33.7 days and a loading rate of 40–60 kg per day (Lastella et al., 2002); and between 49 and 64% for different grass types (Yamamoto et al., 1988). This shows that the methane rate of biogas is in harmony with the other studies. The reason for the lower methane rate in Exp. 1 could be because of using only chicken manure and plant wastes.

Conclusions

There are some problems on fermentation of chicken manure because of its high level of nitrogen. The amount of nitrogen could be decreased before fermentation or the fermentation process should take place at low dry matter contents. These are also increases in the construction costs.

Being low of the required bacteria population necessary for biogas production in the fermentation process of plant wastes and lower rates of bacteria nutriment elements complicates the fermentation process. So, an additional nutriment support is necessary in biogas fermentation of plant wastes for economical production. In this study, optimum conditions for chicken manure and plant wastes were determined at specified conditions and duration time, dry matter content, and temperature conditions were obtained.

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