A NOVEL PROCESS DESIGN FOR ENHANCED BIOGAS PRODUCTION FROM POULTRY MANURE USING A SOLAR WATER HEATING SYSTEM

ALI R.[1] and AL-SAE'D R.[2]

Institute of Environmental and Water Studies, Birzeit University, P. O. Box 14, Birzeit, Palestine
[1]E-mail: rowaydasali@gmail.com, [2]E-mail: rsaed@birzeit.edu

ABSTRACT

This paper analysis the enhancement of biogas production from poultry manure using a small scale anaerobic digester assisted by a solar water heating system in a Palestinian poultry farm. The farm, located in Ramallah district, with a total area of 140 m^2 and accommodating around 1800 birds every 50 days produces annually about 6.57 tons (18 kg/day). An anaerobic digester with a design volume of 0.5 m^3 and a working capacity of a 0.3 m^3 was fed by poultry manure (total solids: 20%, C:N ratio: 32:1) in a continuous mode. A solar water heating system circulated water within the digester to enhance the anaerobic digestion process. The daily biogas yield ranged from 80 to 300 L and the methane content of the biogas ranged between 46% and 66%. As substitute to natural gas, the biogas with heat generated of 777 MJ was directly used for onfarm heating purposes during the study period. Digester monitoring during the winter period revealed that biogas production rate increased by 33% and the temperature increased by 50% by using solar system. The fresh anaerobically digested slurry showed a nutrient rich fertilizer (NPK ratio of 1:1.3:1.3). Solar drying tank enhanced the removal of fecal pathogens (*F. streptococcus*) up to 3 log10. The economic profitability is expected to increase, making the capital investment worthwhile to farmers as of free-cost feed.

Keywords: anaerobic digestion, methane, poultry manure, hot water solar system

1. Introduction

Poultry manure management for the production of biogas as a renewable energy source is an important issue around the world (Wilawan *et al.,* 2014). This source of energy is regarded as cheap and clean (Thu *et al*., 2012). The poultry production sector in Palestine contributes the biggest of the gross agricultural output and the most important agricultural sector (PCBS, 2013). Palestinian farmers accumulate large quantities of manure produced by poultry farms adjacent to their farms. This presents the current disposal methods causing environmental problems. Palestinian rural communities suffer from limited energy sources with around 80% of its energy demand come from neighboring countries (Ismail *et al.,* 2013). According to Abu Hamed *et al.,* (2012), the conversion of animal waste into biogas has the potential to meet 20% of the populations needs in rural areas. The conversion of unused agricultural residue into biodiesel could replace 5% of the imported diesel. Therefore, sustainable management of poultry manure requires effective treatment technologies for energy recovery. Upflow anaerobic sludge bioreactor (UASB) was used for anaerobic digestion of poultry manure by Yetilmezsoy and Sakar (2008). Currently, several engineering biogas designs are applied for anaerobic digestion of different substrates. Khoiyangbam *et al.,* (2011) reported increased biogas production using poultry manure as a feedstock, where operating temperature played a key role in the anaerobic digestion process. In this study a novel process design is developed using a solar water heating system to maintain mesophilic bacterial conditions for optimal biogas production. The aim of this study is to investigate the impacts of using a solar system on the biogas production rates and evaluate the feasibility of the anaerobic digestion of poultry manure at a small-scale in a Palestinian farm.

2. Materials and methods

2.1. Plant design, operation and monitoring

This study was carried out on a small family owned chicken farm in Beit Our Al Foqa village of Ramallah district. Beit Our has a Mediterranean climate with a monthly average temperature ranging from 7.5 to 10 °C in the winter up to 30 °C in the summer. The chicken farm has a total area of 140 m^2 accommodating about 1800 birds every 50 days. The annual output of waste and manure from the chicken farm is around 6.57 ton. Natural gas was used to heat the farm in winter season before installing the biogas system.

The study started from May, 2014 until February, 2015 with daily routine monitoring of process temperature, pH, and biogas flow rate. The startup period was monitored by measuring the volatile fatty acids and the alkalinity. Solar hot water system was used to increase the system temperature and enhance the anaerobic process a long study period (October-February).

The biogas plant entailed five main units: mixing tank, fermentation tank, hot water solar system, biogas storage balloon, and digested slurry (solid waste collective tank) as depicted in Figure 1. Both mixing and digestion tanks have a 0.5 m^3 volume and were built above the ground from high-quality plastic materials. The material of connecting pipes and valves are resistance to physical and chemical stress that may be caused by the slurry and biogas. The mixing tank, solid chicken manure was mixed with the same amount of water, before entering the anaerobic digestion tank. To prevent settling and allow manual agitation periodically, the process design considered agitation in both mixing and digestion tanks using an iron-made agitator with small brushes installed at the top of the reactor.

The temperature within the digester was controlled by thermometer sensor at mesophilic range (35-45°C). The pH (6-8) of the slurry was monitored daily using a pH meter. The biogas flow rate per cubic meter was measured by gas rate flow meter, at this time the content was heated by solar heater to enhance the fermentation process.

The biogas was collected in a 250 L balloon made of adequate material (ethylene propylene dienemonomera) and has 3 days storage capacity. Anaerobically digested slurry was placed in an iron-made collector for sun drying and solar disinfecting. Final product was scraped and stored in plastic bags to avoid excess of sun drying and losing nutrients.

The anaerobic digester volume was calculated based on the organic loading rate (OLR) to accommodate the daily amount of manure produced by the farm (18 kg) and the degradation rate of the slurry. The OLR describes as the amount of feed processed per unit of the reactor volume per day and expressed in kilograms TVS per day and per m^3 digester (kg TVS/m^3.day). In this study, the OLR started by 2.5 kg TVS/m^3.day, raised up to 6 kg TVS/m^3.day within time.

The temperature of the digester was controlled and kept mesophilic (30–45°C) using recirculated thermally heated water produced by the solar unit. The solar unit consisted of a solar collector device (flat plat collector with 1.6 m^2 area), pump, pipes, and helix heat exchanger. The solar collector served as a heat exchanger for the thermally heated water.

Considering the system storage capacity (1-3 days), the anaerobic digestion tank was operated in a continuous feeding mode by a fully homogenized slurry (water mixed chicken manure). As chicken manure has a high total solid content (20%), it was mixed with water (1:1 ratio), resulting in a recommended slurry with 12% total solid concentration by weight (Khoiyangbam *et al.,* 2011). During the start-up phase, the anaerobic digester was fed by a mixture including chicken (20%) manure amended by cow (70%) manure and anaerobic sludge (10%). Lab analysis (volatile fatty acid and alkalinity) were measured weekly during a one-month start-up phase (results not shown).

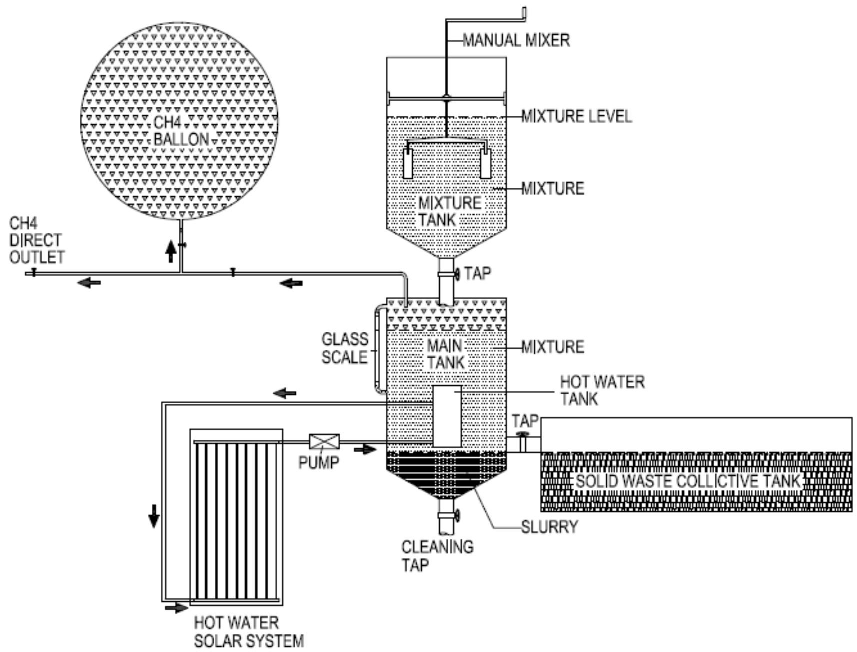

Figure 1: Schematic diagram of the anaerobic digestion system**.**

2.2. Sample analysis

All experimental analysis of this study was generated in the laboratory at Birzeit University. Solid chicken manure, seeding materials and slurry were analyzed for total solids (TS), total volatile solids (TVS). TS, TVS, chemical oxygen demand (COD) total organic carbon (TOC), total Kjeldahl nitrogen (TKN), and C:N ratio were measured according to the Standard Methods (APHA, 1998).

Regular samples of digested slurry were collected once a week during the startup period and analyzed for volatile fatty acids (VFA), and alkalinity according to German Standards (VDI 4630) and ISO 566713 standards. Chemical (NPK) and microbiological (Total coliforms, *E. coli, Streptococcus faecalis*) parameters were measured on fresh digested slurry and sun dried digested slurry (three samples each). Analysis of NPK for biofertilizers was determined by Gravimetric method according to (ISO 11885 by ICP-OES). The amount of biogas produced was daily measured using a gas flow meter. Biogas composition (CH_4/CO_2) was analyzed at the Royal Scientific Society, Amman, Jordan, using a biogas analyzer (BioGas Check CDM).

2.3. Energy production

The energy production in this study was observed to evaluate the potential energy produced in from the biogas system to evaluate the economy of the process. Biogas is directly used for farm heating purposes as a substitute of natural gas, according to (Khoiyangbam *et al*., 2011) one cubic meter of biogas with 60% methane is equivalent to 4713kcal or 4.698 kWh electricity. In this study the total annual amount of the biogas was 39.42 m^3; the mount of the energy from those quintets was calculated.

3. Result and discussion

3.1. Feedstock and slurry characteristic

The characteristic of feedstock (solid chicken manure), seeding materials (cow manure and anaerobic sludge), and slurry are illustrated in Table 1. The chicken manure feed stock had a high total solids (TS) content compared with seeding materials and feed slurry.

Table 1: Solid waste and seeding characteristics**.**

Parameter	Chicken manure	Slurry	Cow	Sludge
TS (%)	85.4	12.5	30.3	29.0
TVS (%)	87.8	97.5	93.4	92.6
COD (mg/L)	70473.7	43368.4	23894.7	3105.3
TOC (mg/L)	16396.5	23472.1	1124.2	2104.6
TKN (mg/L)	502.6	769.5	57.7	169.9
C:N	32.6	30.5	19.5	12.4
pH	7.2	7.4	8.2	6.7

The anaerobic digestion process and biogas production in the digestion tank depend on both process configuration and waste characteristics. Nutrients and C:N ratio are crucial parameters to ensure a stable digestion process and fertilizer quality (Crolla *et al*., 2013). The C:N ratio for solid chicken manure was 30 suitable for anaerobic digestion process (Khoiyangbam *et al*., 2011). Compared to Cow manure and anaerobic sludge, the C:N ration of the chicken manure (33) and the slurry (30) indicated sufficient nutrients for the anaerobic process.

The measured values for volatile fatty acids (VFA) and alkalinity of the slurry were in the range of 0.3–0.4, indicating a stable anaerobic digestion process with no potential for acidification (Murphy *et al*., 2013). During the second week of operation, the pH value dropped below 7 indicating accumulation of VFA in the digester, then increased after this week. During the start-up phase, the highest concentration of VFA was recorded at lowest pH of 6.5 and remained constant (800 mg/L) at a stable pH range (7-7.8) by the end of the first month of operation.

3.2. Biogas generation and composition

Biogas production is a primary indicator for biogas plant efficiency. The biogas flow was measured along the period of plant operation, which started from 1 of May to 28 of February. It was noted that biogas began produced immediately after seeding; the first production was at (23 May). During the first 4 weeks, there was no feeding applied since the biogas production was increasing gradually, then it was sharply increased in the fourth week; after that production of biogas was fluctuated (Figure 2). Likewise, biogas quality was tested by burning on 26 may and it was not burn, flowing this day the biogas was burned with blue flame that indicate a high quality of the biogas. The highest volume of biogas production was (312 L/day). The daily and cumulative biogas production are shown in Figure 2. The trend of accumulative gas production is figured out to provide the better explanation of the relationship between daily gas productions versus time. It is clearly seen that the volume of gas is increase with the longer operational days indicating the good performance of the reactor.

In this study two main bioresources are recycled from installed biogas digester, the biogas (energy) and the digested slurry (fertilizer), where the biogas was directly used for onfarm heating purposes as a natural gas substitute. The calculated amount of heat generated from the biogas produced was 185787 Kcal (equivalent to 777 MJ). The effluent released from the biogas is also an excellent fertilizer. It was noticed that the biogas flame has a blue color reflecting high methane content, while digested and sun dried slurry showed a dark-brown color and odorless, which can be used as a bio-fertilizer to improve soil properties and increase crops yields. The volume and the composition of the biogas are key factor in fermentation process performance. Daily average of biogas production was about 110 L. However, a cumulative trend of biogas was obtained as straight pattern reflecting a constant production rate. The percentage of methane in biogas produced ranged between 46-60% during the first days of September. It was shown the amount of Carbon dioxide is fluctuated and some time was closed to the mount of methane. The methane average of five measurements was about 60%, which coincides with values reported in the literature (Khoiyangbam *et al.,* 2011).

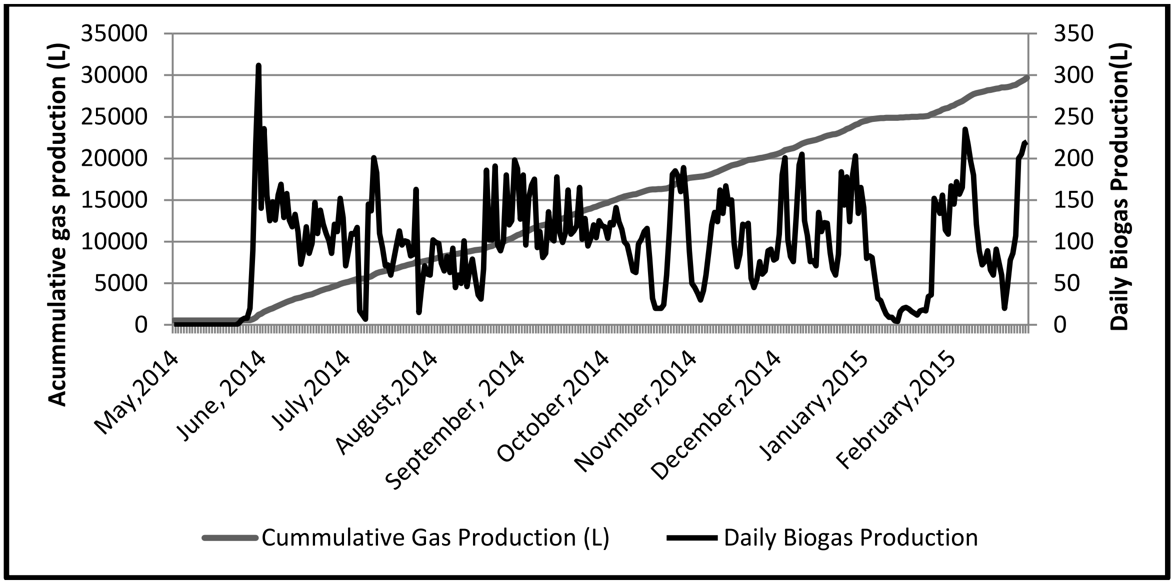

Figure 2: Daily and cumulative gas production during biogas plant operation (May-February)

The daily biogas production has ranged from 80-300 liters, an average of 110 liters per day. The quantities of the biogas were produced from daily digested of 15 kg of fresh chicken manure; that shows every kilogram of organic waste produce more than 1 kg of biogas, and the amount of amount of heat produced from biogas equivalent to 19.7 MJ/m^3, which equivalent to 5.5 kW/m^3. The thermal solar system has increased both digester temperature and biogas production rate.

3.3. Impact of the temperature on the anaerobic digestion

Results of this study indicate that solar energy can be used for the digester heating and it can rise the temperature in the winter season and increase the production rate of the biogas. The temperature of the digester was daily monitoring along the study period of the plant operation. In order to observe the effect of the solar system on the digester temperature and biogas production; the impact of the solar system on the digester temperature and the rate of the biogas was observed in the winter season which is from October to March, along these five months ambient temperatures and solar radiation started to decrease; the solar system using in these five months in order to increase the temperature of the digester and enhance the anaerobic process. The relation between the digester temperature and the biogas production are shown in (Figure 3). Fluctuations in the temperature of the digester were small at summer season (May-September), which being more fluctuated in winter season (October-March).

The highest temperature in summer was 50 °C in June and the lowest was 30°C in September. While, the lowest temperature of the digester in January which was 10°C (a snowy day), and the highest temperature was 45°C (in a sunny day). The annual average temperature of digester in the summer was 40°C, while in winter was 33°C.The daily average of biogas production in summer reached 110 L compared to 100 L during winter. The increase in biogas production rate was attributed to an increase in the digester temperature. The largest daily volume (235 L) of biogas was measured at 45°C during sunny days in January, while the lowest biogas volume (4 L) was at 10°C in snowy day in January. In this study, the winter months (84 sunny days), the average temperature of the digester days was 39°C with total daily average of the biogas production 133 L. During the sunny days, heated water was circulated in the digester, while during rainy days (67 days) the daily average of biogas production was 57 L with an average temperature of 26°C. The impact of the solar system on biogas production rate was elucidated by comparing the averages of temperature and biogas produced in sunny days with those in the rainy and snowy days during winter season. The solar system has increased the biogas production by 33% during the summer due to an increase (50%) in the digester temperature.

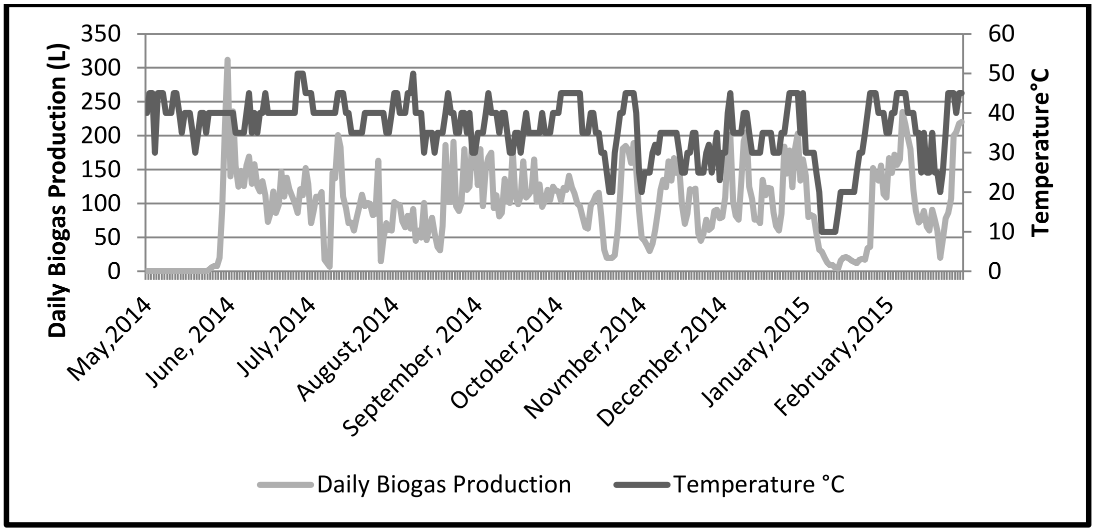

Figure 3: the relationship between the biogas production and the digester temperature.

4. Conclusions

Poultry manure proved a suitable substrate for the installed biogas system and produced on average 110 L biogas per day. The daily biogas generation increased with increased temperature caused by circulated heated water from the solar system. The heat energy resulted from the quantity of biogas produced satisfied the energy demand of the chicken farm during winter period. The digested slurry from the anaerobic digester has chemical and microbiological quality rendering it as excellent fertilizer. Anaerobic digestion and sun-drying processes were able to destroy most of pathogens present in the slurry. The financial affordability of the biogas system, as a zero-waste engineering and environmentally sound system warrants further study.

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