In: Proceedings 14th Int. Conf. Environ. Sci. Technol., 3-5 Sep., Rhodes, Greece.

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

Rowayda Ali[1] and Rashed Al-Sa`ed[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 on farm 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 [29]. Energy production from solid waste is a sustainable strategy to address the worldwide energy and climate change challenges [12, 25]. Biogas produced from animal waste is widely used as a renewable energy source [5], this source of energy is regarded as cheap and clean [27]. Poultry manure is being used as feedstock for biogas digesters [30]; this manure is consisting not only from bird extra, but also may have feathers, and small wood chips [7].

The poultry production sector in Palestine contributes the biggest present of the gross agricultural output and the most important agricultural sector [18]. There are, many chicken farms that have a bad environmental situations [23]. These farms especially in Palestinian villages are producing a lot of manure every months and this manure accumulates near the farm which has caused severe environmental and soil problems [9], including fly breeding, odours, nuisance and greenhouse gas emission if not disposed of or managed appropriately [3]. Not only the accumulation of poultry manure cause air pollution put also pollution of soil and water with nutrients, pathogens and heavy metals that occurs where manure is stored [21]. Odour emissions soil, and water contamination, caused by a large number of contributing compounds including ammonia, carbon, sulphide and phosphorus [26].

Palestine is also suffering from less of energy sources [16]. The Palestinians are depending on external sources to meet their energy demands. Around 80% of their energy sources come from neighbouring countries [11]; it relies on Israel for 100% of its fossil fuel imports and for 87% of its electricity imports. The conversion of animal waste into biogas has the potential to meet the needs of 20% of the rural population [20]. The conversion of unused agricultural residue into biodiesel could replace 5% of the imported diesel [1]. Therefore, sustainable management of poultry manure requires effective treatment technologies for energy recovery [14].

Several biogas designs are now used in the world, which matched with different substrates [22]. Upflow anaerobic sludge bioreactor (UASB) was used for anaerobic digestion of poultry manure [31]. Currently, several engineering biogas designs are applied for anaerobic digestion using poultry manure, Khoiyangbam et al. [19] was reported that the biogas production increased by using poultry manure as a feedstock; where operating temperature played a key role in the anaerobic digestion process [8], because they can directly affect the activity of microbial population and the biogas production [10].

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 Study Site

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 site was selected to be close to the farm, in order to reduce the loss of pressure in the gas lines and to keep cost low.

2.2 Experimental method

The study starts from May 1, 2014 and run until February 28, 2015. Daily routine monitoring like temperature, pH, and biogas flow rate was done along the study period. The start-up period also was monitored by measuring the volatile fatty acid and the alkalinity. Solar hot water system was used in the digester to increase the temperature and enhance the anaerobic process a long winter season, which is start from October to February, since the temperature in those months starting to fall, then the impact of solar energy on rates of anaerobic fermentation was followed up.

2.3 Biogas system design

The biogas system entailed five main units: mixing tank, fermentation tank, hot water solar system, biogas storage balloon, and digested slurry (solid waste collective tub) as depicted in (Fig .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.

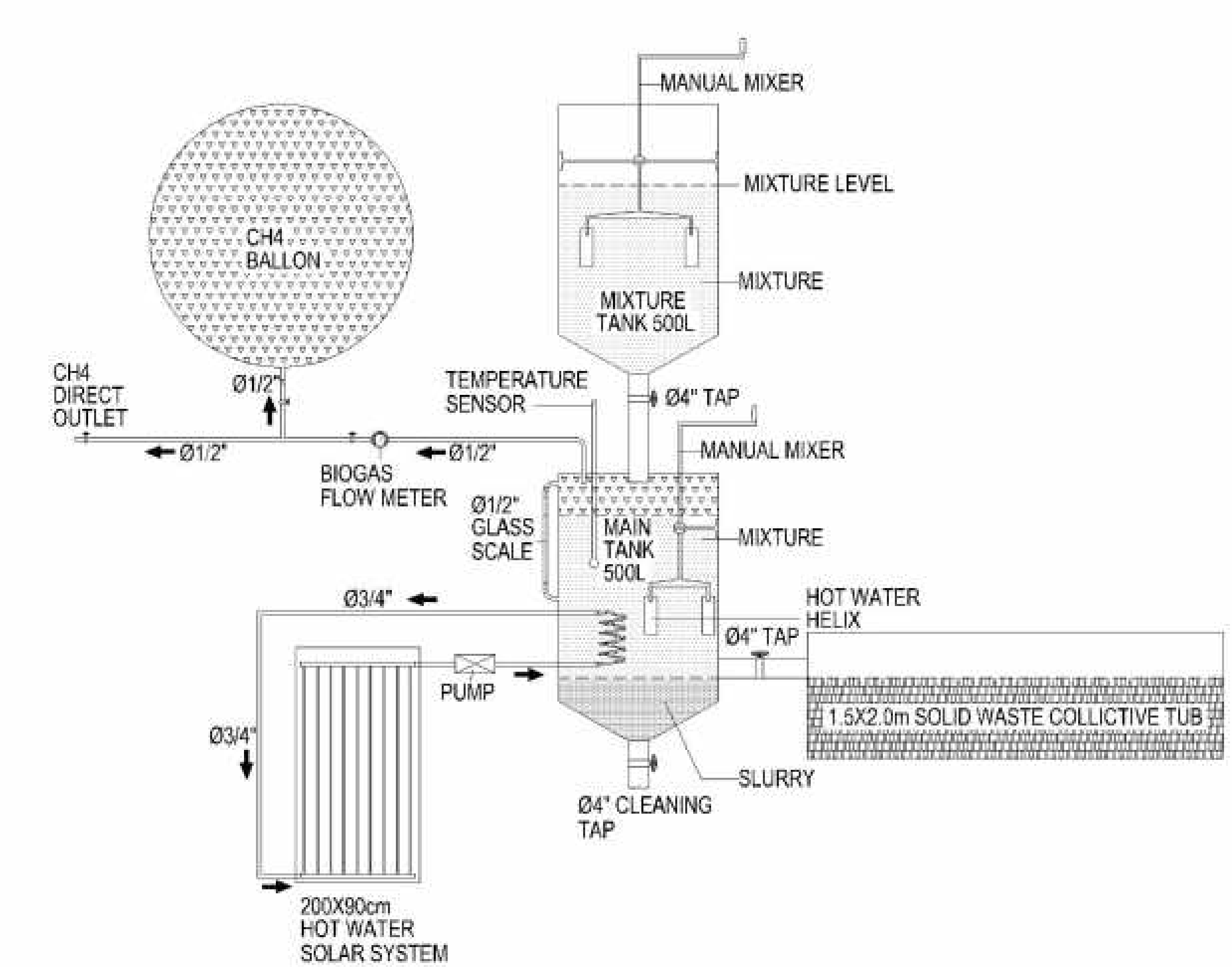

Fig. 1 Schematic diagram of biogas system

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 produced biogas was collected in a 250 L balloon made of adequate material (ethylene propylene dienemonomera), which is connecting to the main digester through a nonreturnable valve; the materials of balloon was chosen to be resistant to pressure, UV radiation, temperature variations and harsh weather conditions. The storage volume was chosen to fit with biogas production rate; it 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 [2].

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) [17]. 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 [19]. 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 of start-up phase.

2.4 Samples analysis

All experimental analysis of this study was generated in the laboratory at Birzeit University. Total solids (TS), total volatile solids (TVS), chemical oxygen demand (COD), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), and C:N ratio were analysed for Solid chicken manure, seeding materials (cow & sludge manure), and slurry. All these parameters were measured according to the (APHA) Standard Methods [4].

Regular samples of digested slurry were collected once a week during the start-up period and analysed for volatile fatty acids (VFA), and alkalinity according to (VDI-4630) German Standards [28]. Triplicate samples for each fresh digested slurry and sun dried digested slurry were analysed for chemical (NPK) and microbiological (Total coliforms, E. coli, Streptococcus faecalis). Analysis of NPK for bio-fertilizers 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 analysed at the Royal Scientific Society, Amman, Jordan, using a biogas analyser (BioGas Check CDM).

2.5 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; one cubic meter of biogas with 60% methane is equivalent to 4713kcal or 4.698 kWh electricity [19]. 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 feedstock 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 [6]. The C:N ratio for solid chicken manure was 30 suitable for anaerobic digestion process [13]. Compared to Cow manure and anaerobic sludge, the C:N ratio of the chicken manure (33) and the slurry (30) indicated sufficient nutrients for the anaerobic process.

Volatile fatty acid and the alkalinity of slurry were determined every week during the first month of the start-up. (Table 2), illustrates the reading by date for VFA and alkalinity of the digestate. Volatile fatty acids/alkalinity was greater than 0.3–0.4, that means an anaerobic digestion process was stable and no risks of acidification according to Murphy et al. [15].

Table 2 Slurry characteristic during start-up period

Date	VFA (mg eq. acetate /L)	Alkalinity (mg $CaCO_3$/L)	VFA/Alkalinity mg/L
May 8, 2014	1722	15240	0.1129
May10, 2014	1567	14560	0.1076
May17, 2014	800	14830	0.0539
May24, 2014	720	14513	0.0446

pH variation with VFA and alkalinity during the started up period are shown in (Fig. 2). pH was measured daily. However during the second week of operation, pH value was below 7. This is because of accumulation of the fatty acids in the digester, then pH start to increase after this week. The highest concentration of VFA was with the lowest pH of 6.5. After that, pH of slurry was stabilized in the small range between 7 and 7.8. While VFA concentration was increased at the first few days then dropped gradually and thereafter remains constant in the range 800 mg/L as the indication of the balance condition of the anaerobic system (Table 2). From day 14 to day 29 of May, the pH and alkalinity value were relatively stabilized and biogas begun produced.

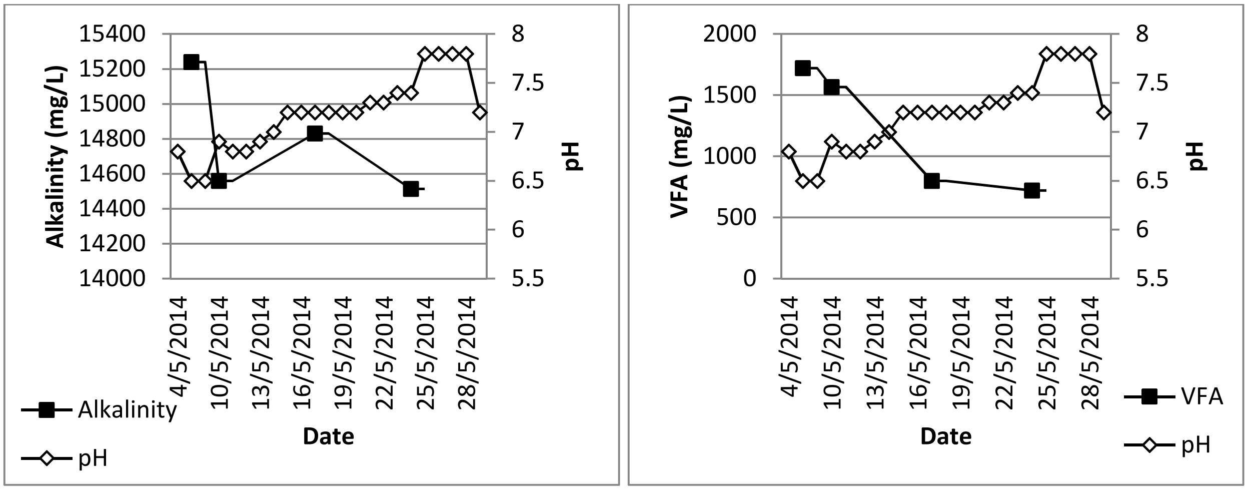

Fig. 2 Variation between pH with volatile fatty and alkalinity acids

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 using biogas flow meter, 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 (Fig. 3). 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. Average of biogas production was approximately 110L/day. However, cumulative of biogas was obtained in the straight pattern indication of biogas remain generated daily. The highest volume of biogas production was (312 L/day). The daily and cumulative biogas productions are shown in (Fig.3). 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.

Methane concentration in biogas and composition of the biogas produced in terms of methane and carbon dioxide content was observed five times in the first days of September; and it was range between 46 to 60% of biogas produced. 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 [19, 24]. It was shown the amount of Carbon dioxide is fluctuated and some time was closed to the mount of methane. The methane average was approximately 60%, where it is within the acceptable value according to Khoiyangbam et al. [19].

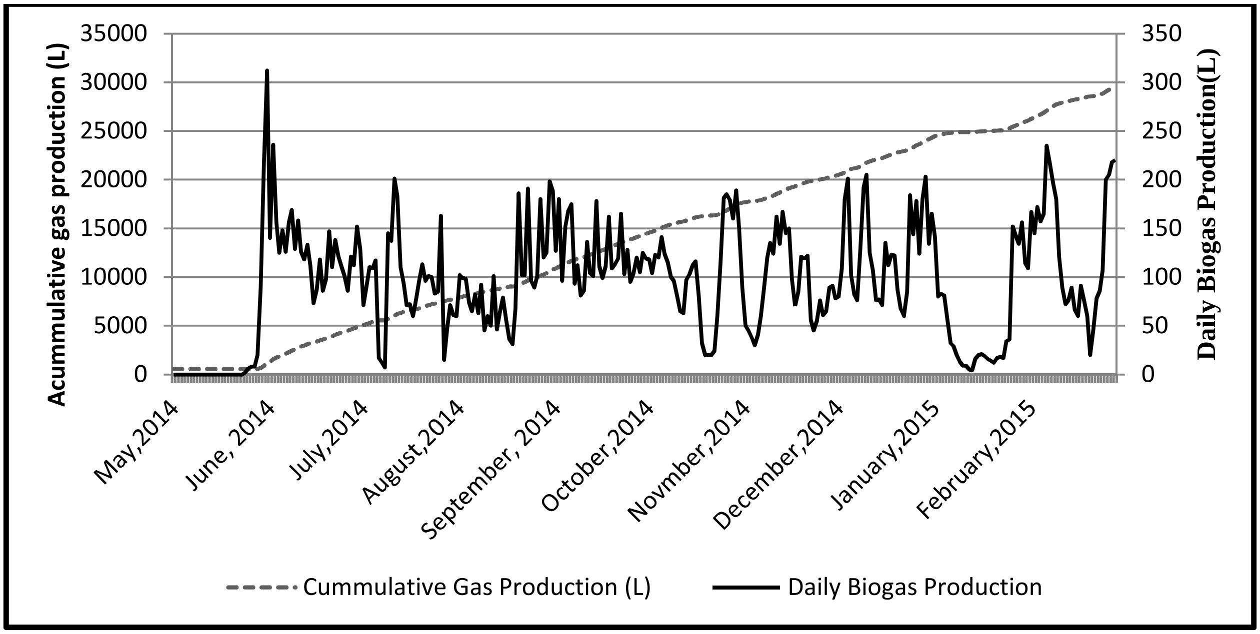

Fig. 3 Daily and cumulative gas production during biogas plant operation (May-February)

3.3 Bio-fertilizer Quality

The digested effluent of the biogas production process can have values as fertilizer or soil amendment. Due to the removal of carbon during anaerobic digestion process results in organic materials that are rich in nitrogen and phosphorus. In this study, the 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 digestate quality depends on the quality of the feedstock that enters the digester, the retention time (time in which the feedstock spend in the digester), and the temperature inside the digester. In this study the chemical parameter were measured for dry digestate samples and compared with the fresh slurry samples (Table 3), which illustrates the nitrogen, phosphorus, potassium, carbon/ nitrogen ratio and pH value in digestate samples during the first four months of plants operation. As shown these analysis results as obtained, the anaerobic digestion and sun drying reduced the nitrogen content in feedstock. Likewise, the increasing the phosphorus and potassium was found. A decrease of nitrogen concentration in the digestate was due to bio-conversion to ammonia gas which is volatilizing during the sun drying. For potassium and phosphorus, were higher due to the fact that some solid have been converted to biogas, resulting in higher nutrient concentration. The chemical parameter values were compared with guidelines to be used as a soil conditioner.

Table 3 The characteristics of digestate slurry

Samples	N%	P_2O_5%	K_2O%	C:N	PH
Fresh sample	2.86	1.03	1.87	30	7.95
Sample 1 (first of June)	2.31	2.35	2.31	23	7.84
Sample 2 (first of July)	2.12	3.02	3.51	22	7.46
Sample 3 (first of August)	1.90	2.82	2.52	24	7.32
Standard [19]	1.4-1.8%	1.0-2.0%	0.8-1.2%		

Another important criterion is pathogen concentration in the digestate. The feedstock may have pathogens which can cause diseases for both animals and humans. Anaerobic digestion is able to kill most of common pathogens present in the feedstock mixture inside the digester; the activation of pathogens depends on temperature and retention times of feedstock inside the digester. Drying of the slurry after digestion process is also kills most of pathogens and reducing odors. In this study, E. coli, Streptococcus faecalis, and Total coliform were selected as indicator organisms in order to represent the efficiency of anaerobic dictions process, those microorganisms have a high heat tolerances and resistance. A reduction of the amount of Streptococcus faecalis per gram biomass of 3–4 log 10 units is an indicator that the temperature and retention time in the digester able to destroy most of the pathogens such as Salmonella sp. and Pestivirus and other parasites such as Ascaris [5].

Three samples were taken respectively at the first three months from plants operation, these samples were taken after drying of the slurry under the sun light (Table 4), on the other hand fresh slurry sample was also taken to measure the reduction of indicator microorganism through the anaerobic digestion process at mesophilic temperature.

Table 4: The biological characteristics of the digestate slurry

Samples	Total coliform(CFU/g)	E.coli	Streptococcus faecalis (CFU/g)
Fresh sample	32000	4700	144000
Sample 1 (first of June)	Nil	Nil	44000
Sample 2 (first of July)	Nil	Nil	3100
Sample 3 (first of August)	Nil	Nil	830

As shown in (Table 4) the sun drying was able to destroyed all cells of E.coli and total coliform within the different retention time of the samples, where Streptococcus faecalis was more resistance to heat and sun light, the drying was reduced it from 144000 to 830 CFU/g; that means the anaerobic digestion with mesophilic temperature and sun drying can be able to kill the pathogens from the digestate improving the human health and minerals values. This is attributes make the anaerobic digestion slurry and effluent to be more accessible for plant utilization and an excellent fertilizers.

3.4 Energy production

In this study the total amount of the biogas was 39.42 m^3; which was directly used for farm heating proposes as substitute of natural gas, these quantities of the biogas were produced from daily digested of 150kg of fresh chicken manure; that shows every kilogram of organic waste produce more than 1 kg of biogas. The calculated amount of heat generated from the biogas produced was 185787 Kcal (equivalent to 777 MJ); this amount is 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.

3.5 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 (Fig. 4). Fluctuations in the temperature of the digester were small at summer season (May-September), which being more fluctuated in winter season (October-March).

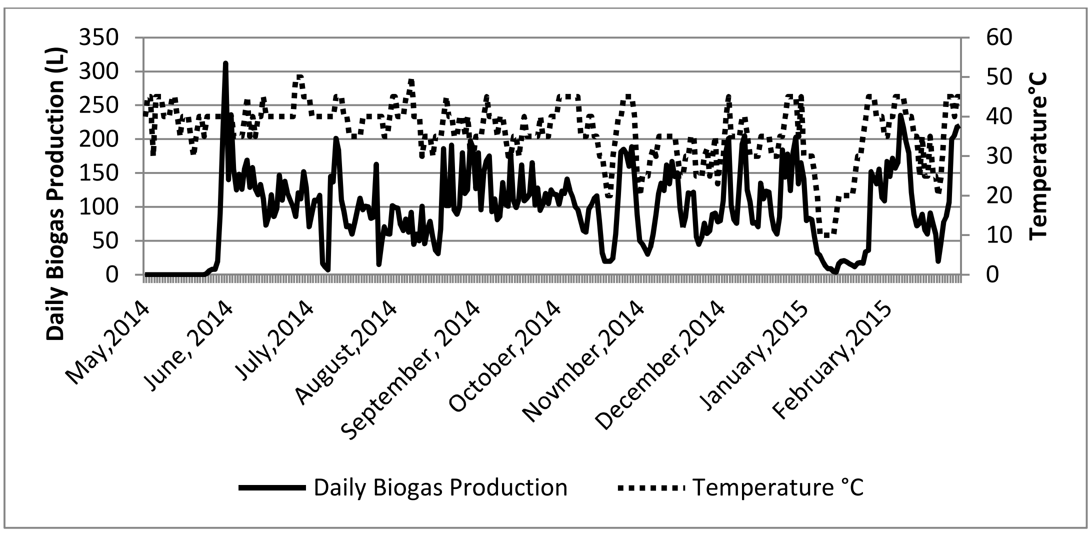

Fig. 4 the relationship between the biogas production and the digester temperature

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.

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 zero-waste engineering and environmentally sound system warrants further study.

Acknowledgment

This research study was funded by Birzeit University. Lab analysis for biogas composition by the staff at the Royal Scientific Society, Amman, Jordan is acknowledged.

5 References

[1] Abu Hamed, T., Flamm, H., and Azraq, M.: Renewable energy in the Palestinian Territories: Opportunities and challenges. *Renewable and Sustainable Energy Reviews* 16, 1, 1082–1088 (2012)

[2] Abubaker, J., Cederlund, H., Arthurson, V., and Pell, M.: Bacterial community structure and microbial activity in different soils amended with biogas residues and cattle slurry. *Applied Soil Ecology* 72, 171–180 (2013)

[3] Adeoye, G. O., Sridhar, M., and Mohammed, O. E.: Poultry Waste Management for Crop Production: Nigerian Experience. *Waste Management & Research* 12, 2, 165–172 (1994)

[4] American Public Health Association.: *Standard Methods for theExamination of Water and Wastewater*. United Book Press, Baltimore, Maryland (1998)

[5] Biosantech, T. A. S., Rutz, D., Janssen, R., and Drosg, B.: 2 - Biomass resources for biogas production A2 - Baxter, Arthur WellingerJerry MurphyDavid. In *The Biogas Handbook : Woodhead Publishing Series in Energy*, T1 - 2 - Biomass resources for biogas production A2 - Baxter, Arthur WellingerJerry MurphyDavid, Ed. Woodhead Publishing, 19–51 (2013)

[6] Crolla, A., Kinsley, C., and Pattey, E.: 13 - Land application of digestate A2 - Baxter, Arthur WellingerJerry MurphyDavid. In *The Biogas Handbook : Woodhead Publishing Series in Energy*, T1 - 13 - Land application of digestate A2 - Baxter, Arthur WellingerJerry MurphyDavid, Ed. Woodhead Publishing, 302–325 (2013)

[7] Dalkılıc, K. and Ugurlu, A.: Biogas production from chicken manure at different organic loading rates in a mesophilic-thermopilic two stage anaerobic system. *Journal of Bioscience and Bioengineering* 120, 3, 315–322 (2015)

[8] Feng, R., Li, J., Dong, T., and Li, X.: Performance of a novel household solar heating thermostatic biogas system. *Applied Thermal Engineering* 96, 519–526 (2016).

[9] Gutarowska, B., Matusiak, K., Borowski, S., Rajkowska, A., and Brycki, B.: Removal of odorous compounds from poultry manure by microorganisms on perlite – bentonite carrier. *Journal of Environmental Management* 141, 70–76 (2014)

[10] Hassanein, A. A., Qiu, L., Junting, P., Yihong, G., Witarsa, F., and Hassanain, A. A.: Simulation and validation of a model for heating underground biogas digesters by solar energy. *Ecological Engineering* 82, 336–344 (2015)

[11] Ismail, M. S., Moghavvemi, M., and Mahlia, T.: Energy trends in Palestinian territories of West Bank and Gaza Strip: Possibilities for reducing the reliance on external energy sources. *Renewable and Sustainable Energy Reviews* 28, 117–129 (2013)

[12] Kaspersen, B. S., Christensen, T. B., Fredenslund, A. M., Møller, H. B., Butts, M. B., Jensen, N. H., and Kjaer, T.: Linking climate change mitigation and coastal eutrophication management through biogas technology: Evidence from a new Danish bioenergy concept. *Science of the Total Environment* 541, 1124–1131(2016)

[13] Khoiyangbam, R., Kumar, S., Jain, M., Gupta, N., Kumar, A., and Kumar, V.: Methane emission from fixed dome biogas plants in hilly and plain regions of northern India. *Bioresource Technology* 95, 1, 35–39 (2004)

[14] Lönnqvist, T., Sanches-Pereira, A., and Sandberg, T.: Biogas potential for sustainable transport – a Swedish regional case. *Journal of Cleaner Production* 108, Part A, 1105–1114 (2015)

[15] Murphy, J. D. and Thanasit Thamsiriroj.: 5 - Fundamental science and engineering of the anaerobic digestion process for biogas production A2 - Baxter, Arthur WellingerJerry MurphyDavid. In *The Biogas Handbook : Woodhead Publishing Series in Energy*, T1 - 5 - Fundamental science and engineering of the anaerobic digestion process for biogas production A2 - Baxter, Arthur WellingerJerry MurphyDavid, Ed. Woodhead Publishing, 104–130 (2013)

[16] Naim, A. and Al-Agha, M. R.: Palestine: RE action plan: Moving away from traditional energy resources. *Refocus* 2, 2, 20–23 (2001)

[17] Nathalie Bachmann, E. S.: 8 - Design and engineering of biogas plants A2 - Baxter, Arthur WellingerJerry MurphyDavid. In *The Biogas Handbook : Woodhead Publishing Series in Energy*, T1 - 8 - Design and engineering of biogas plants A2 - Baxter, Arthur WellingerJerry MurphyDavid, Ed. Woodhead Publishing, 191–211 (2013)

[18] PCBS. *Statictical Data*. *Agriculture*. http://www.pcbs.gov.ps/DesktopDefault.aspx?lang=en (2014).

[19] R S Khoiyangbam, Navindu Gupta, and Sushil Kumar.: *Biogas Technology*. *towards sustainable development*. TERI Press, New Delhi, India (2011)

[20] Rosyidi, S. A. P., Bole-Rentel, T., Lesmana, S. B., and Ikhsan, J.: Lessons Learnt from the Energy Needs Assessment Carried out for the Biogas Program for Rural Development in Yogyakarta, Indonesia. *The 4th International Conference on Sustainable Future for Human Security SUSTAIN 2013* 20, 20–29 (2014)

[21] Saidur, R., Abdelaziz, E. A., Demirbas, A., Hossain, M. S., and Mekhilef, S.: A review on biomass as a fuel for boilers. *Renewable and Sustainable Energy Reviews* 15, 5, 2262–2289 (2011)

[22] Scholwin, F. and Nelles, M.: 9 - Energy flows in biogas plants: analysis and implications for plant design A2 - Baxter, Arthur WellingerJerry MurphyDavid. In *The Biogas Handbook : Woodhead Publishing Series in Energy*, T1 - 9 - Energy flows in biogas plants: analysis and implications for plant design A2 - Baxter, Arthur WellingerJerry MurphyDavid, Ed. Woodhead Publishing, 212–227(2013)

[23] Shen, X., Huang, G., Yang, Z., and Han, L.: Compositional characteristics and energy potential of Chinese animal manure by type and as a whole. *Applied Energy* 160, 108–119 (2015)

[24] Simpson, K.: Animal manure on grassland and fodder crops, fertilizer or waste: by H.G. van der Meer, R.J. Unwin, T.A. van Dijk and G.C. Ennik. Martinus Nijhoff, P.O. Box 163, 3300 AD Dordrecht, The Netherlands, 1987, 388 pp., 240 Dfl/$96.00/£65.75, ISBN: 90-247-3568-8. *Agriculture, Ecosystems & Environment* 33, 4, 403–404 (1991)

[25] Soltani, A., Sadiq, R., and Hewage, K.: Selecting sustainable waste-to-energy technologies for municipal solid waste treatment: a game theory approach for group decision-making. *Journal of Cleaner Production* 113, 388–399 (2016)

[26] Szogi, A. A. and Vanotti, M. B.: Prospects for phosphorus recovery from poultry litter. *OECD Workshop: Livestock Waste Treatment Systems of the Future: A Challenge to Environmental Quality, Food Safety, and Sustainability* 100, 22, 5461–5465 (2009)

[27] Thien Thu, C. T., Cuong, P. H., Le Hang, T., van Chao, N., Le Anh, X., Trach, N. X., and Sommer, S. G.: Manure management practices on biogas and non-biogas pig farms in developing countries – using livestock farms in Vietnam as an example. *Journal of Cleaner Production* 27, 64–71 (2012)

[28] VDI-Gesellschaft Energietechnik., *Standard.: VDI 4630*. *Fermentation of organic materials – characterization of the substrate, sampling, collection of material data, fermentation tests*, Germany (2006)

[29] Wilawan, W., Pholchan, P., and Aggarangsi, P.: Biogas Production from Co-digestion of Pennisetum Pururem cv. Pakchong 1 Grass and Layer Chicken Manure Using Completely Stirred Tank. *2013 International Conference on Alternative Energy in Developing Countries and Emerging Economies (2013 AEDCEE)* 52, 216–222 (2014)

[30] Wu, S., Ni, P., Li, J., Sun, H., Wang, Y., Luo, H., Dach, J., and Dong, R.: Integrated approach to sustain biogas production in anaerobic digestion of chicken manure under recycled utilization of liquid digestate: Dynamics of ammonium accumulation and mitigation control. *Bioresource Technology* 205, 75–81 (2016)

[31] Yetilmezsoy, K. and Sakar, S.: Improvement of COD and color removal from UASB treated poultry manure wastewater using Fenton's oxidation. *Journal of Hazardous Materials* 151, 2–3, 547–558 (2008)