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Original Research Paper

New Factor (Quality of Temperature) Affecting Directly the Biogas Production and Solved by Solar Heating Models

Qiu Ling*(**)†, Amro A. M. Hassanein*(***) and Asli Ayhan****
*Northwest A&F University, College of Mechanical and Electrical Engineering, Yangling, Shaanxi 712100, China
**Western Scientific Observing and Experimental Station for Development and Utilization of Rural Renewable Energy, M.O.A, Northwest A&F University, Shaanxi , China
***Arish University, Faculty of Environmental Agricultural Sciences, El-Arish, North Sinai, Egypt
****Uludag University, Faculty of Agriculture, Bursa, Turkey
†Corresponding author: Qiu Ling

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ABSTRACT

This research focuses on a new parameter that can directly affect the biogas production. The study was carried out in two groups under two different temperature conditions. The first group, outside the door (allow the digester temperature to change according to ambient temperature), and the second is in the control room that support the digester to keep the temperature in balance without fluctuation, however there is no source of heating. Each group has three digesters with different total solid (TS) i.e, 6, 8 and 10% TS. The result shows that the average of the temperatures inside the digesters of the outdoor group (first group) was 29.39°C (52.2°C maximum, and 12°C minimum) compared with the control room group (second group), which was 25.7°C (30°C maximum, and 20°C minimum). However, the temperature in the first group was higher, but biogas production of the second group was more constant and higher. This phenomenon is due to the gas production been significantly affected by variations of temperature inside the digester during the daytime in the first group. This problem could explain the reason of changing the biogas production in biogas digester that does not use any heat source (lagoon, underground digester, etc.). As the temperature decreases sharply, the gas production also decreases sharply. Accordingly, it is difficult to generate large amounts of gas with stable performance without keeping the temperature inside the digesters in balance throughout the whole fermentation days, even though there is no heating source. Therefore, we recommended one of three solar heating models that is able to keep it in balance temperature and, therefore increase the performance of fermentation without daily additional costs.

INTRODUCTION

Growth in the use of fossil fuels means that global CO_2 emissions from energy use have also increased at just as with the fastest rate since 1969 (BP 2011). This directly affects the environment and human health. China occupies the first position in the world ranking for CO_2 emissions with 23.33% of the total global CO_2 emissions, followed by the United States at 18.11% (Division 2010). Carbon dioxide emissions from consumption in China have increased sharply. It was 1550 million tons in 1980 and increased to nearly 8000 million tons in 2009 (Division 2010).

One of the methods to produce clean energy is from biomass and organic matter (Lin et al. 2011), thus anaerobic digesters can attract people's attention because of its energy and environmental benefits (Hassanein et al. 2011). Biogas has the potential to dramatically decrease the emissions of greenhouse gases that pollute the environment (Kotsopoulos et al. 2008, Nishizaki 2009). Biogas used in house-hold scale digesters for lighting and/or cooking, in addition biogas slurry exhibited significantly higher levels of N uptake, agronomic efficiency, and fertilizer N recovery efficiency that can add through irrigation systems (Iida et al. 2010, Ryu et al. 2010, Phayom et al. 2012a).

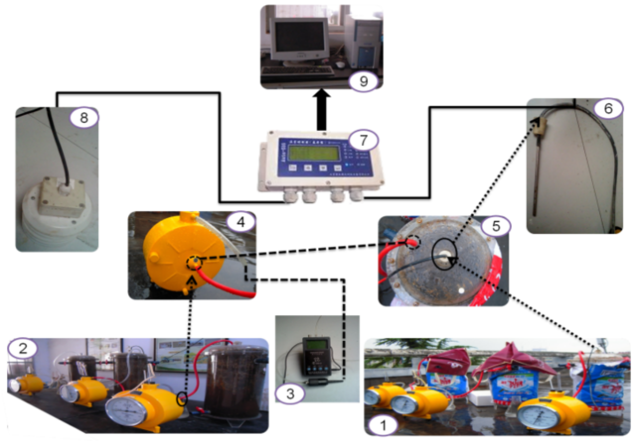
Temperature is one of the most important factors which controls microbial growth rates inside the digester during the fermentation process (Sweeten & Reddell 1985, El-Mashad et al. 2004a). The different temperatures of anaerobic digestion can be divided into four types: normal digestion temperature (10-27ºC) low-mesophilic digestion (30±3ºC) mesophilic digestion (35±3ºC) and thermophilic digestion (55±3ºC) (Safley Jr & Westerman 1992, El-Mashad et al. 2004b, Wu et al. 2006, Deublein & Steinhauser 2008). At low temperatures, methanogenic bacteria are less productive and have a lower growth rate, resulting in low biogas production and methane recovery. The increase of temperature in a range can improve the biogas fermentation effect. On the other hand, digestion at higher temperatures needs less time for the bacterial inactivation and this causes the bacteria to die much faster in thermophilic than in mesophilic digestion (Elmerdahl Olsen & Errebo Larsen 1987).

Alvarez & Lidén (2008) researched the effect of fermentation on llama-cow-sheep manure in a high altitude area. The result showed that the biogas yield increased when the temperature rised. (Boe et al. (2009) researched on biogas fermentation of cattle manure in three continuous-flow stirred tank reactor (CSTR): bioreactor with different temperatures, the highest biogas yield and lowest volatile fatty acids (VFA) accumulation. In research which uses food waste as raw materials (Kim et al. 2006), the biogas yield and COD removal are the highest in thermophilic conditions compared to mesophilic condition. Gerardi (2003) found that, the methane-forming bacteria are active in two ranges of temperatures. These two ranges are the mesophilic range (32 ± 3°C) and the thermophilic range (55±5°C). The methane-forming bacteria are inhibited between 40°C to 50°C, and the digestions performance falters near 42°C. This symbolizes the transition from mesophilic to thermophilic organisms. Sanchez et al. (2000) studied the effect of temperature and pH on CH_4 production using cattle manure. They concluded that the methane production decreased when the temperature was increased from 35 to 60°C with pH values 7.0 and 7.6. This result was most probably due to the higher sensitivity of ammonia inhibition observed in thermophilic processes. Phayom et al. (2012b) investigated the relationships between higher heating values (HHVs) and major constituents (carbon, nitrogen, moisture, ash concentrations) of rice straw, the study indicating that this relationship has the potential for use in estimating HHVs of rice straw.

There are many experiments that studied the effect of certain temperatures on biogas production (Kotsopoulos et al. 2008, Nielsen & Feilberg 2012, Rico et al. 2012), but this research paper is the first one that focused on the fluctuation of digester temperature that can directly affect the biogas production. Thus, the objective of this study is to investigate the effect of changing ambient temperature direction on biogas production and to present a proposal for solving the temperature problem by using solar energy for heating biogas digesters to achieve the optimum temperature for biogas production and improve the productivity efficiency without additional costs.

MATERIALS AND METHODS

The experiment was carried out in two groups under two different temperatures at the northwest station of biogas products and equipment quality center, Ministry of Agriculture, Xi'an, Shaanxi, China. One of these two groups was inside the control room and the second one outside the door. Each group has 3 digesters with different total solids (TS) 6%, 8% and 10% TS.



1: Three digesters out door. 2: Three digesters in control room. 3: Gas board- 3200p . 4: Gas flow meter (LMLF). 5: Digester cover orifices 6: Temperature sensor for organic matter. 7: Auto32 control sensor 8: Ambient temperature sensor. 9: Computer.

Fig. 1: The experiment design and unit setup with measurement tools.

The experimental design and unit setup with measurement tools: The equipment was connected together as shown in Fig. 1. The experiment consists of six anaerobic digesters, divided to three digesters outdoor (first group control), and three digesters inside the control room (second group). The wet gas flow meter was used for measuring the gas yield every day and total gas yield during the experiment period. The Gas board-3200p was used for measuring CH_4, CO_2 and pH. The temperature was recorded every 10 minutes by using the Auto32 Control Sensor, for measuring the temperature of organic matters by the temperature sensors for liquid, and temperature of environment by ambient temperature sensor, all the data are then transferred to a computer.

Biogas digesters: The experiment contained 6 digesters with total volume for one digester being 24 L. Each digester is fabricated with acrylic with 8 mm in thickness, 495 mm length and 250 mm diameter as shown in Fig. 2. Each digester has an inlet and outlet tube for feeding by organic matter and rejecting the digested materials. The digester was provided by three orifices, one at the top of the digester cover to release the produced gas and another for the temperature sensor, and the third in the middle of digester for pH measurement.

The fermentation material and inoculants: The material was 80% of the digestion volume, and the material was wheat straw and inoculants. The wheat straw (*Triticum aestivum*) was taken from the farm of the Northwest A & F University. The wheat straw was cut into small pieces (2mm in length). The inoculants were taken from biogas station, Xi'an, Yangling, China. The experiment included two groups with each group having three digesters with different total solid (TS) 6 %, 8 % and 10 %. The dry organic matter was 75% of

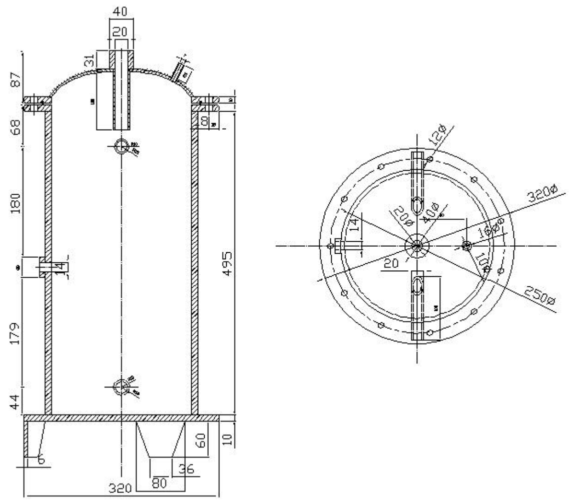


Fig. 2: Schematic diagram of biogas digester.

the total weight of straw. The inoculants dry were 15 % of inoculants total weight and it was 30% of total weight.

Gas production: The gas yield was measured every day automatically by using a gas flow meter. It was connected directly with the gas orifice in the cover as shown in Fig. 1. The gas flow meter records the gas by moving the indicator of the gas meter. Each half revolution in the gas meter equals one litre, meaning that each revolution equals 2 litres of gas and moves the total counter number 2 values. Methane gas and pH measured by using gas board-3200p. The gas sample is taken by connecting the gas board-3200p with output of gas flow meter as shown in plate.

Temperature measurement: Two types of temperature sensors were used for measuring the temperature. Each type has two sensors. The first type used for measuring temperature inside the digesters by using two sensors, each group has one. The second type was used for measuring the ambient temperature by using two sensors for control room and outdoor.

The sensors were connected with Auto32 control sensor as shown in Fig. 1. Auto32 control sensor measures the temperature every 10 minutes and stores the data in internal memory. The data recorded were transferred to computer every 5.8 days. During the experiment, the Auto32 control sensor recorded 12700 numbers during 527 hours.

RESULTS AND DISCUSSION

The results show the effect of changing ambient temperature direction on biogas production. During the experiment the methane gas production (CH_4) ratio in the second group (control room group) was better than the first group (outdoor group). CH_4 ratio in the first group with TS 10%, the minimum was 7.3% and the maximum was 55% compared to 10.5% (minimum) and 70% (maximum) in the second group. For the TS 8% in the first group, the minimum was 13.5% and the maximum was 50% compared to 14.5% (minimum) and 73.5% (maximum) in the second group. Moreover, for TS 6% in the first group the minimum was 11.9% and the maximum was 53% compared to 17.3% (minimum) and 60% (maximum) in the second group.

The relation between ambient temperature and the temperature inside the digesters: As shown in Figs. 3-4 and Table 1 the ambient temperatures of the second group was 32°C (maximum) and 21.5°C (minimum) with average 26.48°C. The temperature inside the digester of the second group was 30°C (maximum) and 20°C (minimum) with average 25.7°C. This means that, the control room tries to stop the changing direction of ambient temperature in addition to controlling the digesters temperature.

The relation between the temperature inside the digesters and gas production: Fig. 5 shows that the biogas has a significant effect of the temperature inside the digester. While the temperature decreases sharply, the gas production also decreases sharply. This phenomenon appears when there is no heating in the cold region.

The marks show the effect of temperature on gas production, the circles show decrease of temperature and the arrows show decrease of gas production, because of the changing direction of temperature inside the digester.

The gas productions from the three digesters were more stable during the experiment period, because the changing temperature in the control room was very limited as shown in figure.

Comparisons between the gas productions with different Ts in outdoor, and control room groups): Through the experiment period, the biogas production in the second group (control room group) was more than first group (outdoor group) as shown in Fig. 5.

Table 1: Temperature direction in first and second groups.

	Ambient temperatures °C			Temperatures inside the digesters °C		
	Maximum	Minimum	Average	Maximum	Minimum	Average
First group (outdoor)	36	15.2	24.36	59.2	12.2	29.39
Second group (control room)	32	21.5	26.48	30	20	25.7

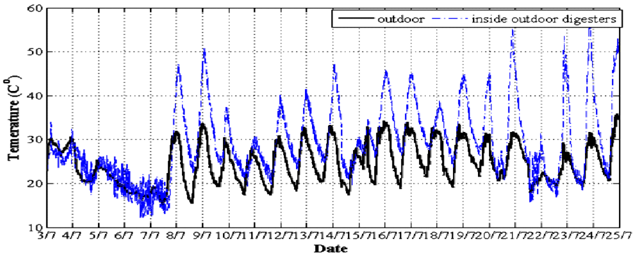


Fig. 3: Effect of ambient temperature on temperature inside the digesters in first group (outdoor group).

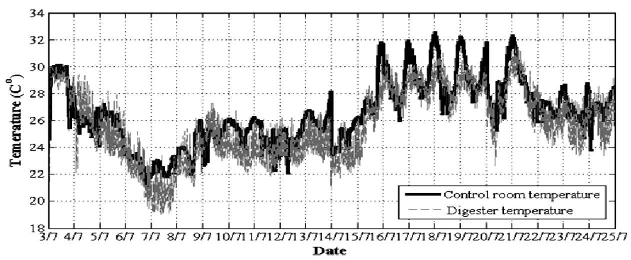


Fig. 4: Effect of ambient temperature of control room on temperature inside the digesters in second group (control room group).

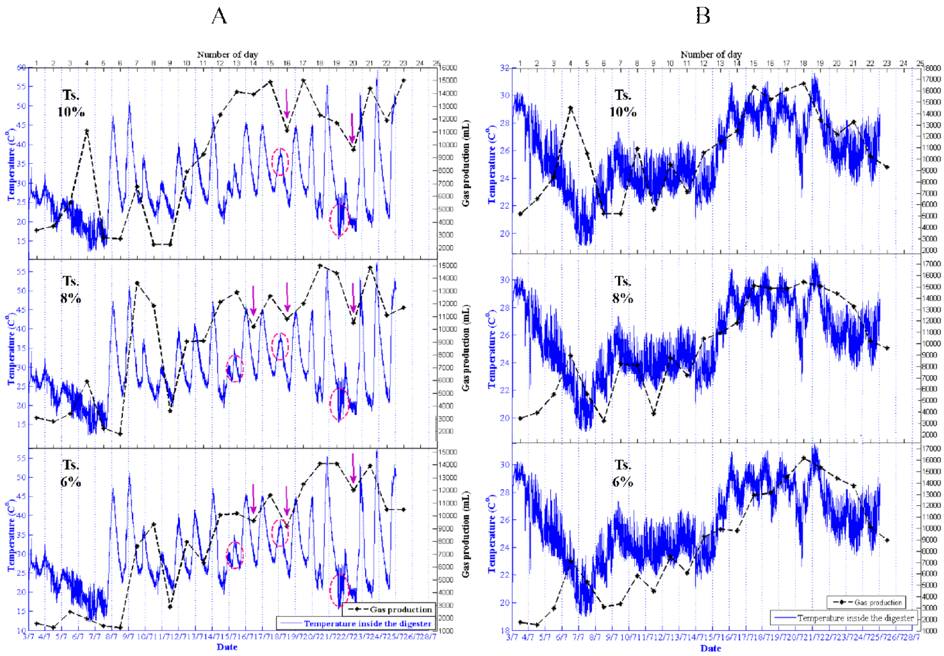


Fig. 5: Effect of changing temperature direction inside digester on gas production. (A: outdoor group and divided to three treatments 6% Ts, 8% TS, and 10% TS. B: control room group divided to three treatments 6% Ts, 8% Ts, and 10% TS)

The gas production was more stable in the second group than the first group because the changing temperature direction was very limited inside the second group compared with the first group, which was very large.

SOLAR HEATING DESIGN TO DEFY THE PROBLEM (FUTURE DESIGNS)

The three designs by the authors are able to create a balance in the temperature during the daylight and the night time, moreover it can increase the temperature of organic matter, therefore, increase the process temperature that increases the performance of fermentation without daily additional costs (Hassanein & Qiu 2013b).

The first design presents the up-ground digester with solar heating system (Fig. 7). The second system consists of greenhouse and solar inlet heating for warming the underground and keeps the digester temperature in balance (Hassanein et al. 2015) as shown in Fig. 8.

The third design system uses parabolic trough solar collector (PTC) with sun tracking system (Hassanein & Qiu 2013a) to maximize solar radiation absorptions is leading to increase the hot water temperature and system efficiency. The greenhouse supplies heating for the digester, plants and animal, as shown in Fig. 9 (Hassanein et al. 2011) .

CONCLUSIONS

The study arrived at the following conclusions:

1. The gas production has been significantly affected by the variations of temperature inside the digester during the daytime. As the temperature decreases sharply, the gas production also decreases sharply.

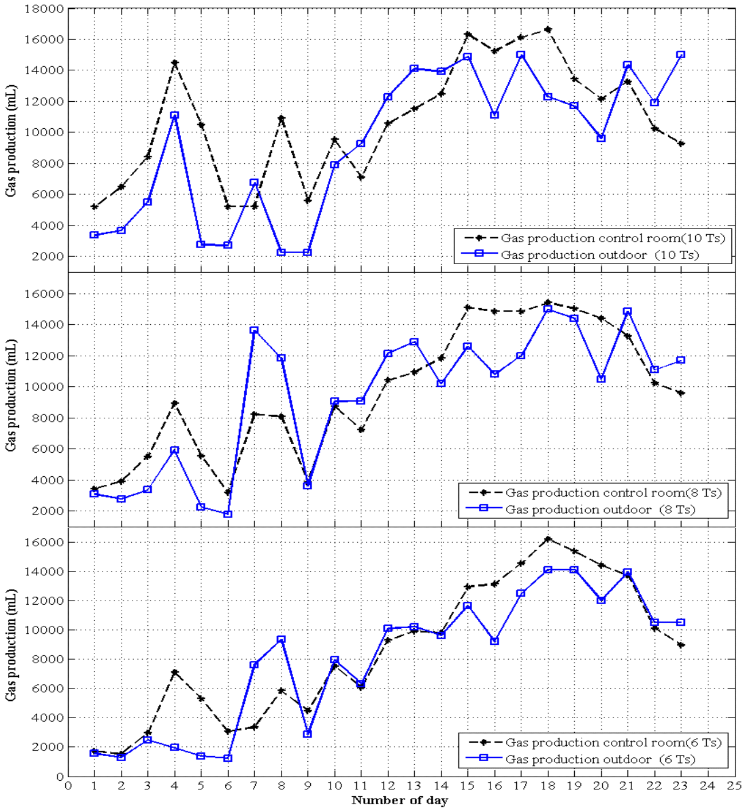


Fig. 6: Comparison between the gas productions in third digesters (6%

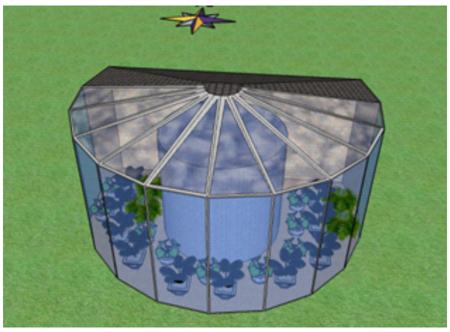


Fig. 7: Schematic first system configuration.

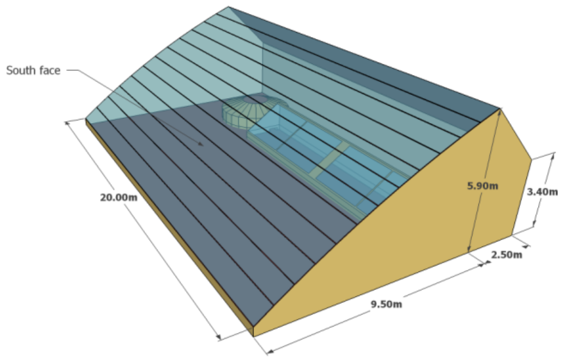
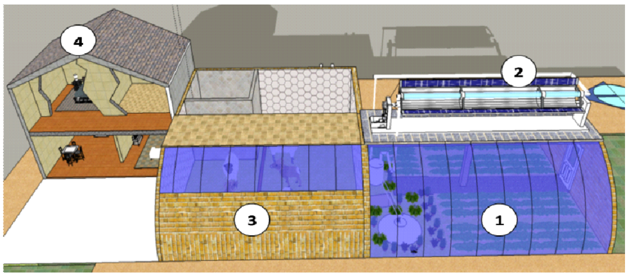


Fig. 8: Schematic second system configuration (Hassanein et al. 2015).

2. The relation between ambient temperature and the temperature inside the digesters is one of the most important factors.
3. Throughout the experiment period, the gas production in the second group (control room group) was more than the first group (outdoor group).
4. It is difficult to generate large amounts of gas with stable performance without keeping the temperature inside the digesters in balance throughout the whole fermentation days.
5. The gas production was more stable in the second group than the first group, because the changing temperature direction was very limited inside the second group compared with the first group, which was very large.
6. We recommend one of the three future designs that are able to solve the temperature problems. Furthermore to keep the temperature in balance and to increase the temperature at the same time, increase the process tempera-



1. Green house 2. Parabolic trough collector 3. Animal part 4. house

Fig. 9: Schematic of third system configuration (Hassanein et al. 2011).

ture that increases the performance of fermentation without daily additional costs.

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