BIOLOGICAL ENGINEERING

EXPERIMENTAL STUDY ON A SOLAR-HEATED BIOGAS DIGESTER USING SHALLOW SOLAR POND IN COLD CLIMATE

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ABSTRACT

In northern Egypt, the ambient temperature almost below 20°C during winter months, which is insufficient for the anaerobic digestion (AD) and affecting negatively the biogas yield, especially for the floating dome digester(Indian model) due to the heat losses through the gas holder. Since the slurry temperature is a crucial factor for the AD rate, this investigation aims to heat a concrete pre-constructed floating dome biogas digester (Family-scale digester) during winter season for enhancing the fermentation rate by utilizing the extracted heat of integrated shallow solar pond (SSP) using dairy cattle dung comparing to a previous work of un-heated digester. The solar-heated digester was evaluated under the same operating conditions of the un-heated digester except the slurry temperature and similar values of both the solar radiation intensity and ambient temperature during 30 days without feeding as a digestion time taking into consideration the slurry temperature, pH, daily, cumulative (m^3/month) and specific (m^3/kg $_{VS}$) biogas yield as well as the total net gained energy. The obtained results revealed that, the average slurry temperature of the solar-heated biogas digester system increased by 12.3°C which led to increase the average daily, cumulative and specific biogas yield by about 129 % higher than the un-heated digester with average methane content of 70% and total net gained energy of 553.1 MJ/month.

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INTRODUCTION

Egypt has 4.2 and 4.95 million head of buffaloes and cattle, respectively **(FAO, 2013)**, thus the anaerobic digestion (AD) process of animal dung for producing biogas is very potential. The growth and activity of anaerobic microorganisms is highly affected by many factors such as the presence of oxygen, pH of slurry, temperature, type of feedstock, stirring as well as the amount of inhibitors **(Al Seadi *et al.*,2008),** which can influence the yield and composition of biogas. AD is affected by temperature **(Chae *et al.*, 2006)** so; temperature is considered a crucial factor for AD as it determines the period and rate of anaerobic degradation process particularly at the hydrolysis and methanogenesis phases. **Nijaguna (2009)** classified the AD into three categories according to the temperature which are called the psychrophilic (< 20 °C), mesophilic (25 to 37°C) and thermophilic (45 to 65 $^{\circ}$C) , where the AD essentially stops below 10 °C. **Gupta et *al.* (1988)** concluded that, increasing the slurry temperature of the bioreactor using solar collector from 20 °C to 35 °C (mesophilic digestion) significantly improved biogas yield for both the dairy manure digestion and co-digestion (manure+ food wastes), but by further increase in temperature to 50 °C resulting in less improvement in biogas production. Due to the initial installation and operation costs of thermophilic digestion are significantly higher than those of mesophilic digestion, thus the mesophilic digestion is more applicable in developing countries **(Wang *et al.,* 2016)**. On the other hand, at temperature below 15 °C, the AD requires more than 75 days as retention time **(Zeeman and Lettinga, 1999)** because the psychrophilic AD in cold climate needs high retention time or large volume of digester. The large volume of the anaerobic digester means high cost of the system construction **(Santosh *et al.,* 2004)**. In northern Egypt and Delta, the average temperature is almost below 20°C (psychrophilic range) during winter season; therefore the rate of AD will be in a lower level due to the inhibition of the mesophilic metabolism microbes which makes the biogas a less reliable energy resource. It is obvious that, the AD is affected negatively by the cold climate, thus some early options for digester-warming technology were investigated which included the charcoal coating of ground around the

digester (**Anand and Singh,1993**), electric heating, oil, biogas heating (**El-Mashad *et al.,* 2004**); coal-fired boiler heating (**Shi *et al.,*2013**); biogas engine-driven heat pump air conditioner (**Xu *et al.,*2010**) ; new type of solar heat pipe (**Jiao *et al.,*2016**) and the hot gas (**Kitamura *et al.,*2007**). The impact of the mentioned heating technologies was very effective, but the high energy consumption means high costs (**Dong and Lu, 2013**). The solar assisted biogas systems including solar collectors (**Zhu *et al.,* 2013**); with temperature sensors and controller (**Li *et al.,* 2014),** evacuated solar thermal collectors (**Zhong *et al.,* 2015**) and the solar salt pond were studied (**Subramanyam, 1989**). These heating systems are expensive, complex and still need to considerable repairing and maintenance. Also, the black-coated translucent plastic with the digester (**Kumar and Bai, 2005**); PVC greenhouse type structure over the gas holder (**Bansal *et al.,*1985**) and biogas plant assisted by solar greenhouse on the par with the conventional brick material (**Kumar and Bai, 2008**) were utilized to accelerate the AD. But these heating methods are somewhat efficient in cold regions due to the low solar radiation and ambient temperature (**Chenglin *et al.,* 2009**). Utilizing clean energy to improve the fermentation temperature and maintain the efficiency of biogas production during winter is widely approbatory (**Lu et *al.,* 2014**).This is can be considered an important target for improving the performance of any biogas production system. So, there is an urgent need to use an inexpensive and simple design solar heater to achieve this target. Regarding the novelty of this work, there is no previous investigation or literature about utilizing the shallow solar pond (SSP) as a solar heater for heating the biogas digester to maintain the AD temperature in the mesophilic range during cold periods. Basically, the SSP can be classified as a solar collector that can be used for collecting and storing heat (**Ganesh and Arumugam, 2016**). The SSP is capable of heating a large quantity of water to appreciable temperature and because of its simplicity in working, it holds out promise for one of the cheapest methods for harnessing solar energy (**El-Sebaii,2005**), so it can be considered as a low cost thermal collector compared to the flat plate and vacuum tube collectors. Hence, the main aim of this work is exploiting the solar energy for enhancing the biogas yield by the integration of SSP with a pre-

constructing floating dome digester during winter season in northern Egypt.

MATERIALS AND METHODS

The practical experiments were carried out at the farm of Experimental and Agricultural Researches Centre, Faculty of Agriculture, Zagazig University, Zagazig city (Lat. 30° $35^{/}$ N, Long. 31° $31^{/}$ E), Egypt. In the present work, the performance evaluation of an integrated SSP with a pre-constructed concrete floating dome biogas digester (Indian model) was performed during a cold period started from January 13th to 12th February 2016 without feeding as a batch process comparing to the performance of the same digester without heating under the same operating conditions such as; the experiment′s region, digestion time, feedstock type, C/N ratio, total solid and the effective volume during the cold period started from December 11th 2015 to 11th January 2016 according to **(Abd allah *et al.,* 2016)**.

1. The experimental setup

1.1 The solar-heated biogas digester

The solar-heated biogas digester consists mainly of: SSP, floating dome biogas digester and heating loop, as shown in Fig.1.

Fig. (1): The Experimental solar-heated biogas digester.

-The SSP:

The SSP was designed and fabricated with a bottom surface area of 2 m^2 with 3cm in depth, glass wool thickness of 5cm as thermal insulator provided with 90° booster mirror according to the recommendations of **(Abd Allah, 2016)**. For exploiting the collected solar heat by the SSP, a black painted serpentine heat exchanger (SHE$_{Pond}$) that made of copper was welded to the upper surface of the pond absorber copper plate and separated with interval distance of 15 cm, outer and inner pipes diameters equal to 1.5 and 0.79 cm, respectively.

-The Floating dome biogas digester:

 The constructed digester is a modified Indian digester model of KIVC that included the digestion chamber, gas holder, manual agitator, mixing and drying basins. To reduce the time, effort and cost for constructing the digester, a pre-constructed cylindrical reinforced concrete digestion chamber was used with volume of 3.68m^3 using dimensions of 3, 1.25 and 0.12m for the height, internal diameter and walls thickness, respectively, with two orifices for the inlet and outlet slurry. The volume of digestion chamber and gas holder (Total volume) was 4.41 m^3 while the effective digestion volume (the slurry height within the chamber was 2.75m) was 3.37 m^3. This chamber provided with a robust metal pipe as gas holder guide with 5.08 cm in diameter. Moreover, the ground level was above about 20cm from the outlet port to permit the digested solution to flow out naturally.

The gas holder made of iron sheet with 0.2 cm in thickness and 1.15 m in diameter with internal sloped blades to break down the scum. At the center of holder, an open ends iron pipe with 7.62 cm in diameter was fixed to help the holder to move vertically through the gas holder guide, whilst an iron pipe at the upper part of holder with 1.83 cm in diameter used to extract the biogas. A propelled agitator with 1.90 cm in diameter and 400 cm in length provided with two sets of pitched blades (3 blades per set) in the lower part of digestion chamber .The agitator diameter was 31.25 cm (25% of the digester internal diameter).The inlet basin was constructed with diameter of 70 cm and depth of 80 cm provided with a manual steel mixer and connected to the bottom of the digester by a

PVC pipe with diameter of 15.24cm, while the outlet basin was constructed for receiving the digested slurry (the effluent).

-*The solar heating loop:*

The solar heating loop depends upon the continuous open-cycle flow mode to transfer the accumulated heat from the SHE_{Pond} in SSP to another serpentine heat exchanger ($SHE_{Digester}$) with similar specifications located at the bottom of digester by recirculating tap water with flow rate of 0.41 L/s using centrifugal pump (90 watt), controlling valve, and hoses. The $SHE_{Digester}$ was coiled vertically in the depth of digestion chamber as a cylindrical shape with dimensions of 80 cm in diameter and 180 cm in height from digester bottom with similar specifications of the $SHE_{Pond.}$

1.2. The feedstock

Fresh dairy cattle dung was collected and analyzed for chemical and physical compositions such as; total solids, volatile solids, organic carbon, and total nitrogen, as shown in Table (1). The initial moisture content of manure was determined in three replicates by drying the samples in an oven furnace at temperature of $105^{o}C$ for 24 hours. At the start of filling, slurry from active biogas digester (microbial starter) was used with volume equal about 5% of the effective volume of digester.

Table (1): Chemical and physical compositions of the fresh cattle dung and Initial slurry

Parameters	Fresh dung	Initial slurry*
Moisture content, % (M.C.)	81.8	92
Total solids, % (TS)	18.2	8
Volatile solids, % (VS)	13.9	6.12
VS, % (from TS)	76.42	75.6
Ash, %	4.3	1.98
Ash, % (from TS)	23.6	24.4
Total organic carbon, % (C)	44.33	43.85
Total Nitrogen, % (N)	1.75	1.85
Carbon/Nitrogen (C/N ratio)	25.3:1	23.7:1
pH value	7.5	7.41

* Slurry before digestion.

2. Measurements and determinations

The Performance evaluation of the solar-heated biogas digester was based on the following indicators:

2.1. The ambient and digester temperatures:

The ambient temperature (^{o}C) was measured by using WatchDog weather station (Model: 900ET, USA), while temperatures of the biogas digester were measured using 8 K-type thermocouple sensors that located every 30 cm from the digester bottom with measuring range of -100 to 1300°C and accuracy of (±0.1% rdg + 0.7°C). The thermocouple sensors were plugged to the multi-channels digital data logging thermometer (Model: TM747 DU 4-Channel, Taiwan).

2.2. The total solids (TS) of slurry:

The cattle dung was mixed with water to reach the recommended value of total solid (TS) content of 8% by using Eq. 3:

$$(Volume \ of \ dung \ \times TS \ concentration)_{before \ dilution} =$$

$$(Volume \ of \ dung \ and \ water \ Mixture \ \times TS \ concentration)_{after \ dilution} \quad (1)$$

$$V_{dung} \times Ts_1 = (V_{water} + V_{dung}) \times Ts_2 \quad (2)$$

$$V_{water} = \frac{V_{dung} (Ts_1 - Ts_2)}{Ts_2} \quad (3)$$

Where:

V$_{water}$:amount of added water to dilute the dung into slurry, kg.

V$_{dung}$:amount of raw material added (fresh dung), kg.

Ts$_1$: total solids of fresh dung, %.

Ts$_2$: required total solids of fermentation material after dilution (8%).

2.3. The pH and C/N ratio

The pH values of the fresh dung, slurry before, during and after fermentation were measured using a digital pH meter (Model pH-201, Taiwan) with 0-14 of measurement range and 0.01 in resolution, as illustrated in Fig.2 (a). The C/N ratios of the dairy cattle dung and the filling slurry were estimated by measuring the total organic carbon and total nitrogen at the analyzing laboratory of Soil Department, Faculty of Agriculture, Zagazig University, Egypt

2.4 The biogas composition

A portable biogas analyzer (Multi-3gases detector, China) was used to detect and analyze the biogas volumetrically with measuring error of $\pm10\%$ and range of 0-100% for CH_4, 0-100% for CO_2 and 1-1000 ppm for H_2S, as depicted in Fig.2 (b).

2.5. The specific daily biogas yield

The biogas daily yield in m^3/day was measured by using a gas flow meter (Model: SENSUS, Egypt) with resolution of 0.001 m^3 and gas flow rate of 0.025-4 m^3/h. However, the specific monthly biogas yield can be determined by using Eq.4 as follows:

$$Specific \quad monthly \quad biogas \quad yield = \frac{Cumulative \quad biogas \ yield \ (m^3 /month)}{TS\% \times VS\% \times \rho \times Effective \quad volume \quad of \quad digester \quad (3.37 \ m^3)} , (m^3/Kg_{VS} .month) \quad (4)$$

Where:

- TS% = total solids for slurry.

- VS% = volatile solids for slurry.

- ρ = density of initial slurry (measured 944 kg/ m³).

2.6. The daily gained energy

The methane has energy value of 37.78 MJ/m^3 (**Murphy and Thamsiriroj, 2013**) and consequently the daily gained energy from biogas yield was calculated using Eq. 5:

$$Daily \quad gained \quad energy = Daily \ biogas \ yield \ (m^3) \times CH_4 (\%) \times 37.78 , (MJ/day) \quad (5)$$

Fig. (2): Measuring devices (a) The pH meter; (b) biogas analyzer.

2.7. The daily required energy

The required energy to operate the solar-heated digester the summation of the energy consumed by the hot water recirculating pump and the manual agitation during the digestion time. The daily consumed energy by the electric motor of the recirculating pump was estimated by using Eq.6:

Daily required energy (for pumps motor) =
$cos\ \varphi \times I \times V \times 10^{-6} \times t$, (MJ/day)   (6)

Besides, the daily required energy for operating the agitator manually was estimated using Eq. 7:

Daily required energy for the manual Agitation =
$P_h \times 10^{-6} \times t$, (MJ/day)   (7)

Where:

   I: current intensity, Ampere

   V: Voltage, (220 V)

cos φ : power factor = 0.7

   P_h: the Agitation power for human (calculated to be 70 W)

 t: daily agitation time, s (4 times per day with total time of 30 minutes/day)

2. 8. The daily net gained energy

The daily net gained energy was calculated using Eq. 8:

 Net daily gained energy = Daily gained energy - Daily required energy ,(MJ/day)   (8)

Finally, the total gained energy (MJ/month) is the summation of daily gained energy for 30 days of the digestion time.

RESULTS AND DISCUSSION

1. Variation of the ambient and slurry temperature for the solar- heated digester

The temperature is a crucial factor affecting the fermentation rate of AD and consequently the biogas production rate. In this work, the monthly average temperature of the circulated water was 20.1°C, in contrast the monthly average temperature of the solar hot water gained by the SSP was 68.5°C during the heated digestion period. According to the previous work results of the un-heated digester (**Abd Allah *et al.,* 2016**); the

average ambient temperature and slurry were 17.3^{o}C and 17.9^{o}C, respectively. A little difference was observed in temperature values inside and outside the biogas digester, as shown in Fig.3(a). Generally, temperature inside the digester was found 0.8-2.8 ^{o}C more which is nearly equal in day, so the AD remained in the psychrophilic range resulting in a very low fermentation rate as well as biogas production, Concerning to the solar-heated digester, the average ambient and slurry temperatures were 21.2 and 30.2^{o}C, hence there is apparent difference was observed in temperature values inside and outside the biogas digester due to the integration of SSP with the digester using the solar heating loop, as illustrated in Fig. 3(b). The obtained results revealed that, the integration of SSP with the biogas digester increases the average temperature of the slurry about 9 ^{o}C over the ambient temperature and about 12.3 ^{o}C over the slurry temperature within the un-heated digester which meant that, the AD altered from the psychrophilic to the mesophilic range. It is evident that, the SSP integration with the digester would increase the microbial metabolism thereby the conversion of the VFA into the desired end product of biogas.
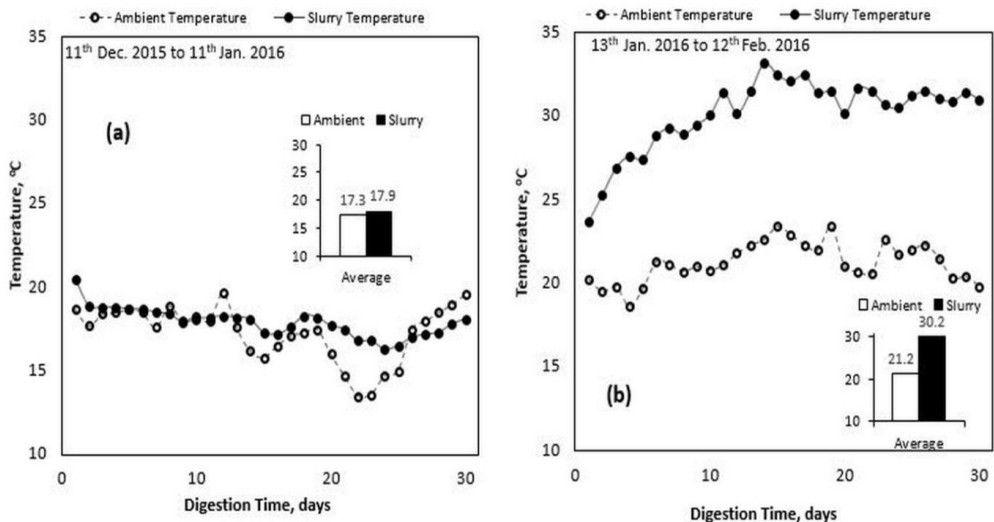
Fig. (3): Average daily variation of the ambient and slurry temperature for (a) the un-heated and (b) solar-heated digester.

2. Variation of influent and effluent pH values for the Solar-heated digester
It is well known that slurry of the anaerobic digestion needs a delicate balance between the rate of hydrolysis and methanogenesis due to of the high sensitivity of methanogenic than acidogenic to volatile fatty acids (VFA) accumulation, where the methanogenic bacteria is in thrive optimally within the pH range of 6.5-7.5. The pH variations of influent and effluent for the solar-heated and un-heated digesters during the digestion period are drawn in Fig. 4. It is clear that, the pH of the influent of the un-heated digester decreased gradually from loading point of 7.4 to 6.8 within the first two weeks, and then it tends to be stable, simultaneously the pH variation of the effluent takes similar trend with higher values due to the presence of ammonia that considered a low methanogenesis. In contrast, the influent of the solar-heated digester abruptly dropped from loading point of 7.4 to 6.4 within the first five days only, as shown in Fig. 4(b).
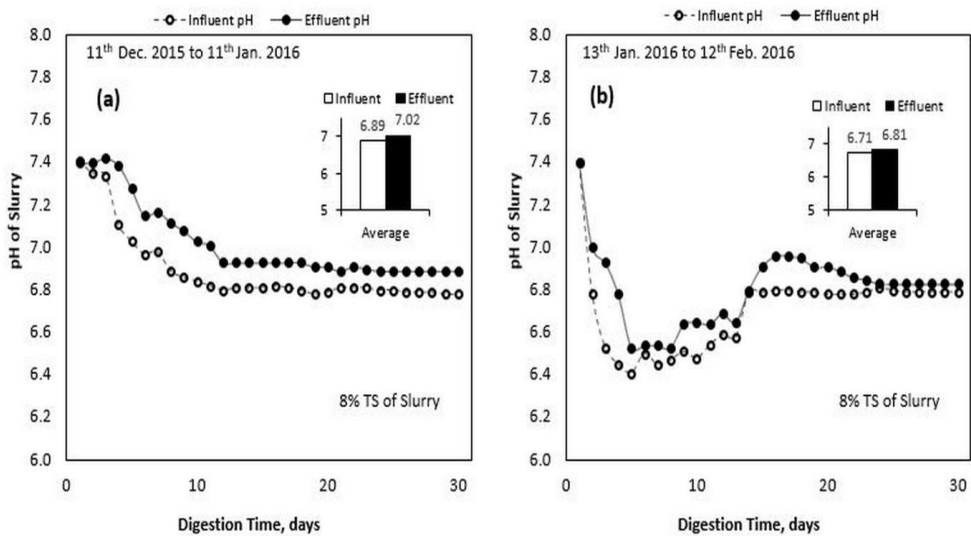
Fig.(4): Daily variations of influent and effluent pH values for (a) the un-heated and (b) solar-heated digester.

This could be referred to the high amount of VFA due to the rise of slurry temperature causing rapid acidification. Afterwards, the VFA were metabolized and the pH increased gradually to reach the peak value of 6.8 at the 13th day, then it tends to be stable around the neutral value of 6.80

till the end of the digestion period. This can be explained by the fact that, the slurry of cattle dung has sufficient buffering capacity producing alkalinity due to the degradation of substrates to neutralize the accumulated VFA that necessary to secure good anaerobic fermentation for enhance the biogas production. Also, the effluent pH values are relatively higher than the pH of the influent but still very close due to the good anaerobic fermentation. Generally, the average influent pH values were 6.89 and 6.71, while the effluent pH values were 7.02 to 6.81 for the un-heated and solar-heated digester, respectively.

3. The daily, cumulative and specific biogas yield for the un-heated and solar-heated biogas digesters

The results of the previous investigation on the performance of the un-heated digester is compared to the obtained data of the solar-heated digester taking into consideration the daily, cumulative and specific biogas yield, as depicted in Fig.5. When the average slurry and ambient temperatures were about 17.9°C and 17.3°C, respectively, the average daily biogas yield for the un-heated digester increased relatively slowly from $0.061m^3$ at the first day to the peak yield of $0.6m^3$ at the 11th day, then the biogas yield was decreased until the lowest yield value of 0.17 m^3 at the end of the digestion time with average daily biogas yield of $0.311m^3$, as shown in Fig. 5(a). It can be noticed that, there was less biogas yield during the first week of digestion that mainly due to the lag phase of microbial growth at the psychrophilic range. As to the influence of the increase the average slurry temperature up to 30.2 °C at ambient temperature of 21.2°C by the integration of the SSP with the biogas digester , the daily biogas yield for the solar- heated digester started from 0.370 m^3 at the first day, afterwards this value increased rapidly with time to reach the maximum yield of $0.997m^3$ at the 12th day, then the biogas yield retarded gradually to about 0.612 m^3 at the end of digestion month with the average daily biogas yield of about 0.711 m^3, as illustrated in Fig.5(b). The cumulative biogas yield for 30 days of digestion time of both the un-heated and solar-heated digester is shown in Fig. 4. It was noticed that, the cumulative yield of biogas yield increased with rapid rate till the

12th day and 14th day for un-heated and solar-heated digester, respectively which followed by a slow rate to the end of digestion time for both digesters, as shown in Fig.5(b).

At the end of the digestion time, the total monthly cumulative biogas yields for the un-heated and solar-heated digester were 9.325 and 21.326 m^3, respectively. Referred to the initially loaded TS of 8%, VS of 75.6% and effective digester volume of 3.37m^3, the specific biogas yield for the un-heated and solar-heated digesters is displayed in Fig.5. The obtained results revealed that, the average monthly biogas yield of one kilogram of VS was about 0.048 m^3/kg-$_{VS}$ and 0.109 m^3/kg-$_{VS}$ for both the un-heated and solar-heated digester, respectively at the day 30 of digestion. From the previous discussion, it can be concluded that the increase of average slurry temperature by about 12.3^{o}C led to increase the average daily, cumulative and specific biogas yield for the solar-heated digester by about 129% more than the un-heated digester. Hence, the biogas yield increases with increases the slurry temperature by securing a stable environment of fast AD and consequently the biogas yield increases substantially due to exponential growth of methanogens.
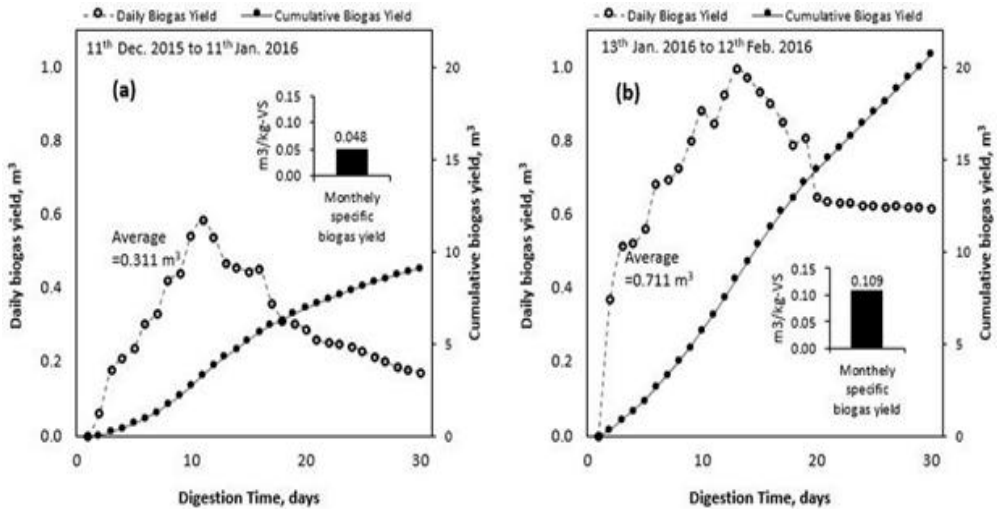
Fig. (5): Daily, specific and cumulative biogas yield for (a) the un-heated and (b) solar-heated digester.

3.5 Biogas composition of the solar-heated digester

As a fact, the increase of biogas yield means more methane (CH_4) will be expected that enhancing the biogas quality. In the present work, the volumetric percentage of constituted gases in the biogas mixture was determined every day during the digestion time. It is well known that, increasing CH_4 content on the account of carbon dioxide (CO_2) and the other gases including the hydrogen sulphid (H_2S) in the biogas is very desirable as an important indicator of the biogas quality. The detected composition of produced biogas for the solar-heated digester during the digestion period is shown in Fig. 6. The obtained data revealed that, the CH_4 content increased gradually on the first few days until the peak methane content of 79% with CO_2 content of 21% and H_2S of 89 ppm at the end of first week, but after the peak period, CH_4 content decreased and reached a steady percentage of 68% at last week of digestion time, simultaneously CO_2 in the headspace gradually increased. The hatched areas in Fig. 6 refer to traces of other produced gases including H_2S that obtained on the first four days of start-up phase and then seems to be in a steady level till the end of experiment. According to the recorded data, the solar-heated digester yielded an average biogas composition of 70, 28 and 2% for CH_4, CO_2 and other gases including H_2S, respectively.
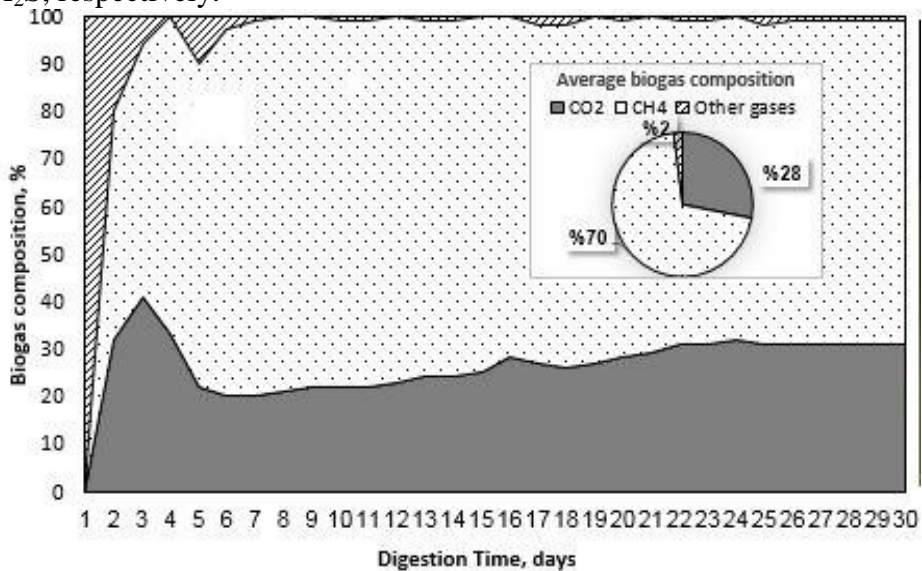

Fig.(6): The biogas composition of the solar-heated digester.

From the previous discussion it is evident that the increase of fermentation temperature contributes in producing high biogas and methane percentage without fluctuation during the experiment.

6. Gained energy of the solar-heated digester

It is necessary to determine the total net gained heat energy during the experiment period to evaluate the potential of the produced energy from the solar-heated digester. Thus, the net gained energy during the experiment period had been calculated based on the daily gained and required energy to describe the net energy value at the end of digestion time, as shown in Fig. 7. Fig. 7(a) show that, the daily gained energy increased from 6.725 MJ to the peak value of 28.259 MJ that occurred on the 12th day from the start of digestion period, and then it is declined to 15.716 MJ at the end of digestion time with total gained energy of 576.3 MJ/month after 30 days of fermentation. On the other hand, the daily required energy depends on the consumed energy in the manual agitation and circulating solar hot water which was about 0.774 MJ/day (23.2 MJ/month).

The data revealed that, the daily net gained energy increased from 5.95 MJ at the beginning of digestion period to reach its maximum value of 27.48 MJ, but it decreases to be 14.942 MJ. Hence, it obvious that the solar-heated digester can add about 553.1 MJ/month as a total net gained energy by the end of digestion period (30 days) as depicted in Fig. 7(b).
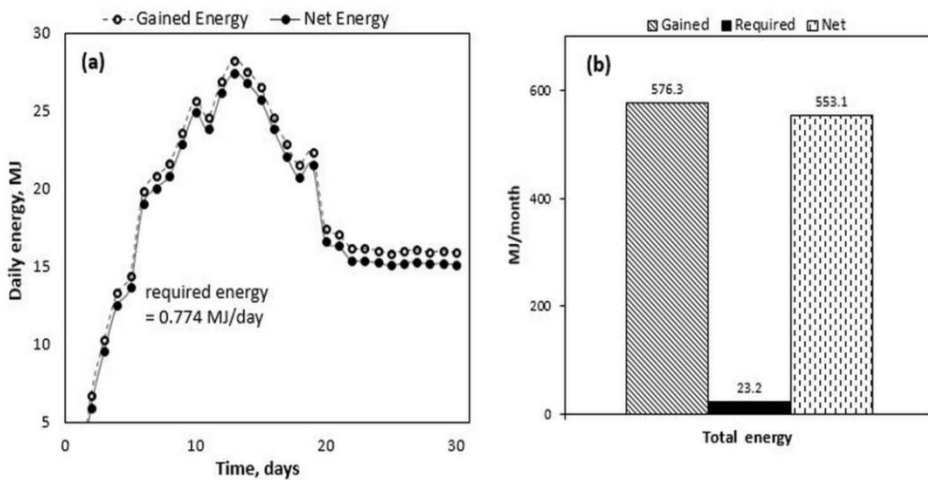
Fig.(7):Gained, required and net energy of the solar-heated biogas digester (a) daily; (b) total.

CONCLUSION

In this work, a solar-heated pre-constructed concrete biogas digester was evaluated through the integration with a shallow solar pond (SSP) compared to the same digester without heating for 30 days of digestion time during winter season using the cattle dung (8% of total solids) in northern Egypt. The SSP integration with the digester increases the slurry temperature by 12.3 $^{\circ}$C over the slurry of the un-heated digester which led to increase the average daily, cumulative and specific biogas yield by about 129% higher than the un-heated digester with total net gained energy of 553.1 MJ/month.

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الملخص العربي

دراسة تجريبية علي هاضم الغاز الحيوي المسخن شمسيا بإستخدام البركة الشمسية الضحلة في المناخ البارد

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في شمال مصر درجة الحرارة غالباً أقل من ٢٠ درجة مئوية خلال شهور الشتاء و التي تعتبر غير كافية لعملية الهضم اللاهوائي و الذي يؤثر بشكل سلبي علي إنتاج الغاز الحيوي وخاصة للهاضم ذو الخزان العائم (النموذج الهندي) بسبب فواقد الحرارة من خلال خزان الغاز. ونظراً لأن درجة حرارة السائل المخمر يعتبر عامل حاسم لمعدل الهضم اللاهوائي،فإن الهدف من هذة الدراسة هو تسخين هاضم خرساني سابق التجهيز ذو خزان عائم (مخمر عائلي) لرفع معدل التخمر في فصل الشتاء من خلال إستخدام الحرارة المستخلصة من بركة شمسية ضحلة متكاملة مع الهاضم بإستخدام مخلفات الماشية الحلابة وذلك بالمقارنة بنتائج سابقة لأداء نفس المخمر بدون تسخين.

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تم تقييم أداء الهاضم المسخن شمسياً تحت نفس ظروف التشغيل للهاضم بدون تسخين بإستثناء درجة حرارة السائل المخمر و عند قيم متقاربة لكل من شدة الأشعاع الشمسي و درجة حرارة الهواء في فترة هضم تصل إلي ٣٠ يوماً بدون تغذية، حيث تم الأخذ في الأعتبار كل من درجة حرارة السائل المخمر، رقم الحموضة، إنتاج الغاز الحيوي اليومي و التراكمي (م^{٣}/شهر)، و النوعي(م^{٣}/كجم مواد طيارة)، بالإضافة إلي   صافي الحرارة الطاقة الكلية. فقد أظهرت النتائج المتحصل عليها أن متوسط درجة حرارة للسائل المخمر داخل الهاضم المسخن شمسياً إزدادت بحوالي ١٢٫٣ درجة مئوية و الذي أدي زيادة كل من إنتاج الغاز الحيوي اليومي و التراكمي و النوعي بنسبة تصل إلي ١٢٩% مقارنة بالهاضم دون تسخين و بنسبة متوسطة لغاز الميثان وصلت إلي ٧٠% وقيمة لصافي الطاقة المكتسبة الكلية ١٠٫٥٥٣ ميجاجول/شهر.