POTENTIALITY OF BIOGAS PRODUCTION USING ANAEROBIC DIGESTER WITH STRUCTURAL DEVELOPMENT AT LOWER AND UPPER EGYPT IN WINTER

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ABSTRACT

This work presents structure development for a family-scale floating dome anaerobic digester for producing biogas represents in using pre-constructed concrete digestion chamber instead of the conventional digester in attempt to reduce the time and costs of construction. Also, the digestion performance of the developed digester was evaluated during winter season to investigate the potentiality of producing rich-biogas yield at Lower of Egypt (LoE) as a cold region and Upper of Egypt (UoE) as more temperate region by building up two identical digesters using dairy cattle dung. Furthermore, feasibility of the produced biogas was performed to determine the cost of the biogas energy unit comparing to the cost of energy unit of other energy sources. The obtained data revealed that, using of the developed digester at UoE led to increase the average daily, cumulative and specific biogas yield with about 40.20, 45.78 and 44.08%, respectively higher than the digester at LoE, in addition to a remarkable increment in daily and total gained biogas energy by about 46.64 and 51.40%, respectively with high average methane yield of 70.52%. From economic point of view, the developed digester reduced the time and total cost of construction with about 86.67% and 41.32%, respectively comparing to the conventional digester with the same volume and design. Additionally, the cost per biogas energy unit for the developed digester at LoE and UoE were 0.014 and 0.007 EGP/MJ, respectively which are lower than the actual costs (not subsidized) per energy unit of natural gas (the lowest price of energy unit in Egypt) by about 85.41% and 92.7 %, respectively according to 2018 prices. Ultimately, the developed digester has a good prospective economically and on the level of digestion performance, especially in temperate regions

Keywords: *Biogas, pre-constructed digester, winter season, dairy cattle dung, digestion performance, feasibility of biogas*

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INTRODUCTION

Energy is considered the main drive of the development towards progress, and flourishment on the level of economy, education, health and lifestyle in any country. The renewable energy resources are playing a vital role to diminish the terrible and hazard impact of fossil fuels on the environment to protect the globe from the expected climatic disasters in the next few decades which will be caused by such fuels. Biomass as an important kind of renewable energy represents the major energy resource for the people in rural areas in Egypt **(Abd Allah *et al.*, 2016)**, which including animal and poultry wastes, crop residues, agro-industrial wastes and other types of biomass materials**.** The concept of utilizing the biomass as a potential renewable energy resource to produce heat, electricity, and power become more ambitious **(Atyia *et al.*, 2017)**. Biogas energy is a clean and sustainable form of energy that could be used as an alternative to fossil fuels **(Surroop and Mohee, 2012)**. The main raw material used to produce biogas in Egypt is the dung of buffalo and cattle animals. Actually, Egypt has 19.9 million head of livestock and animals **(CAPMAS, 2016),** while Egypt has 8.115 million head of buffaloes and cattle **(FAO, 2018)**, this means huge quantity of cattle and buffaloes manure. Simultaneously, storage of manure in open air generates CH_4 and CO_2 by anaerobic self-remediation of manure which can strongly contribute to the global warming **(Neshat *et al.*, 2017)**. Additionally, the stored cattle dung is considered an attractive environment of pathogens as well as bad pungent odor. Methane emissions can be avoided by treating manure in biogas facilities where methane can be recovered and converted to green fuel **(Rico *et al.*, 2014).** Hence the exploiting of cattle and buffaloes manure to produce the biogas as a gaseous bio-fuel using the bioprocess of anaerobic digestion (AD) becomes one of the most prospective routes towards a world free of pollution. Among hundreds types of traditional anaerobic digesters, three of them are most efficient; namely, floating dome, fixed dome and plug flow (tubular) digester (**Bond and Tempeleton, 2011)**. The floating dome digester or the Indian style is the popular type in Egypt due to its simplicity in repair and maintenance. The stability of the anaerobic fermentation process within the digester 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)**.When all operation parameters are stable, the conventional biogas digesters particularly the common digester of floating dome in Egypt is suffering in the winter season from the reduction of the biogas yield **(Abd El-Wahab *et al.*, 2017)**. Many attempts by many researchers were executed to heat up the slurry inside the digester during the winter season, but all heating systems have high energy consumption that means high costs **(Dong and Lu, 2013)**. Additionally, the anaerobic fermentation is slow process in general and hence a large hydraulic retention time (HRT) of 30–50 days is used in the conventional biogas digesters which lead to a large volume of the digester and consequently high cost of the system construction **(Santosh *et al.*, 2014)**. However, the upper of Egypt (UoE) is considered more temperate region in the daylight comparing to the Lower of Egypt (LoE) during the cold period of year which means the conventional digester probably has advantage for producing high yield of biogas. Accordingly, the main aim of this work is developing the construction of a conventional family-scale biogas digester in attempt to reduce the initial installation costs and consequently the producing cost of the biogas energy unit as well as investigate the performance of the developed digester at Lower and Upper Egypt during the winter season.

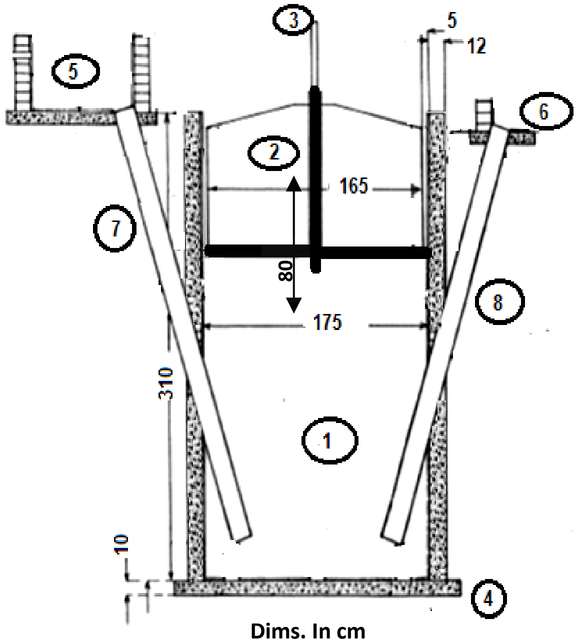
MATERIALS AND METHODS

Two identical developed family-scale biogas digesters without heating were constructed, installed and evaluated at two different regions throughout 60 days of fermentation in two consecutive winter seasons started from November 11th 2017 to January 9th 2018 for the experiment in LoE and from November 11th 2018 to January 9th 2019 for the experiment in UoE using anaerobic mono-digestion as a batch process. The evaluation of the two digesters including the performance under different ambient temperatures and the effect of the developed structure on the producing cost of the biogas. The practical experiment in Lower Egypt was carried out at private farm at Abou Kabir city (*Lat. 30^o 35$^/$ N, Long. 31^o 31$^/$ E*), Sharkia Governorate, while the experiment in Upper Egypt was performed at El-Shiekh Essa Village, Qina Governorate (*Lat. 26^o 10$^/$ N, Long. 32^o 43$^/$ E*). The performance of the two digesters was evaluated under the same operating conditions such as; digestion time, type of substrate, total solids, while the C/N ratio of the used substrate in the two regions was lied in the recommended range of 20:1 to 30:1 given by (**Yen and Brune, 2007)**.

1. The experimental setup

1.1 The developed biogas digester

Two identical developed floating-dome digesters were constructed and assembled at the experimental sites in LoE and UoE regions by the domestic labors using local raw materials and fittings. Both of digesters are family-scaled and very similar on the level of materials types, digester design, dimensions, total volume and effective volume even the technique of the construction. The developed digester is a modified structural KIVC digester with partition wall. Basically, this digester included the digestion chamber, gas holder, agitator, mixing and effluent basins, as illustrated in Fig.(1). It is known that the construction of digestion chamber using bricks for the conventional digester takes long time, great effort, experienced labor and high cost. In attempt to overcome the mentioned problems with the conventional digester, the developed digester was made from a pre-constructed cylindrical reinforced concrete digestion chamber with volume of 7.46 m^3 with dimensions of 3.10, 1.75 and 0.12 m for height, internal diameter and walls thickness, respectively. The gas holder provided with inclined iron blades to rid of the scum and vertical pipe at top surface of holder with 1.90 cm (3/4 inch) in diameter used to flow out the biogas. The gas holder made of iron sheet with total volume and thickness of 1.70 $m^3$and 2 mm respectively, and then it painted with anti-rust layer and black matt paint. The gas holder can move up and down by a vigorous metal pipe called the holder guide that made with 2.54 cm in diameter and 1.25 cm in length. The total volume of the developed digester was 9.16 m^3 with an effective volume of 6.2 m^3. Furthermore, the cylindrical mixing basin was constructed above the ground level with about 20 cm with 80 cm in diameter and 50 cm in depth using cement lined bricks and provided with a manual steel agitator. The concrete base of the rectangular outlet basin allocated under the ground level with about 20 cm to permit the nature flow of the digested slurry. The mixing and outlet basins were connected to the bottom of the digestion chamber with two PVC pipes with 15.24cm (6 inch) in diameter



Part No.	Part Name
1	Pre-constructed concrete digestion chamber
2	Gas holder
3	Holder guide
4	Concrete base
5	Feeding basin
6	Outlet basin
7	Slurry inlet pipe
8	Slurry outlet pipe

Fig. (1): Schematic diagram of the developed biogas digester.

1.2. The used substrate

In this work , dairy cattle dung has been used as substrate that collected freshly from two private domestic cattle sheds located nearby the experimental sites at LoE and UoE. The initial slurry was analyzed to determine the physiochemical properties of initial slurry (inffluent) on the basis of total solids of 8% in the both regions, as depicted in Table (1). The moisture content (MC), total solids (TS), volatile solids (VS) and ash were determined by drying the samples in an oven furnace at temperature of 105^{o}C for 24 hours throughout three replicates at the poultry production laboratory, Fac. of Agric., Zagazig Univ., Sharkia Governorate for the experiment in LoE, while the samples analysis for the experiment in UoE was carried out at the Provincial laboratory for soil fertility, Directorate of Agriculture, Qina Governorate. The anaerobic digestion within the two digesters was started without microbial starter supposing the default state that there are no active biogas digesters at the two experimental sites.

2. Measurements and determinations

The performance of the two developed digesters was evaluated with taking into consideration the following indicators:

Table (1): Physiochemical properties of the cattle dung Initial slurry

properties	Initial Slurry of cattle dung *	
	Lower Egypt	Upper Egypt
Moisture content, % (M.C.)	92.00	92.00
Total solids, % (TS)	8.00	8.00
VS, % (from TS)	76.20	79.6
Ash, % (from TS)	23.80	20.4
Total organic carbon, % (C)	44.25	46.17
Total Nitrogen, % (N)	1.78	1.97
Carbon/Nitrogen (C/N ratio)	25:1	23.5:1
pH	7.6	7.9
Density, kg/m^3 (ρ)	990	975

** Slurry before digestion.*

2.1. The ambient and digestion temperatures

The ambient and digestion temperatures (ºC) were measured by using K-type thermocouples (measuring range of -100 to 1300°C and accuracy of ±0.1% rdg + 0.7°C) that connected to a four-channels digital data logging thermometer (TENSMARS TM747-DU,Taiwan). Regarding the digestion temperatures, the thermocouples sensors were located every 30 cm from the digester bottom for monitoring the temperatures of the different layers of slurry.

2.2. Total solids (TS) of slurry:

The recommended value of total solid (TS) content of 8% in the dairy cattle slurry (inffluent) can be reached by using the following relation given by **Abd Allah (2016)**:

(mass of dung×TS_1)$_{\text{before dilution}}$ = (*mass* of dung-water mix×TS_2)$_{\text{after dilution}}$

$$m_{dung} \times Ts_1 = (m_{water} + m_{dung}) \times Ts_2$$

$$m_{water} = \frac{m_{dung}(Ts_1 - Ts_2)}{Ts_2}$$

Where:

m_{water}= mass of added water to dilute the dung into slurry, kg.

m_{dung} = mass of 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 of slurry

The pH values of digested slurry during fermentation period were measured using a digital pH meter (Model pH-201, Taiwan) with measurement range of 0-14 of and 0.01 in resolution. The total nitrogen was determined by using method. The C/N ratio of the dairy cattle slurry before digestion was estimated by measuring the total organic carbon and total Kjeldahl nitrogen.

2.4. Daily, cumulative and specific biogas yield

The daily biogas yield (m^3/day) was measured by using a gas flow meter (Model: SENSUS- Egypt) with resolution of 0.001 m^3.Thereafter, the daily cumulative biogas yield (m^3) by adding the daily biogas yield to the previous day yield for the whole consecutive days throughout the digestion period (60 days).Accordingly, the specific biogas yield can be estimated by using the following equations given by **Abd Allah (2016)**:

$$\text{Specific biogas yield} = \frac{Cumulative\ biogas\ yield\,(m^3/60day)}{TS\% \times VS\% \times \rho \times Digester\ effective\ volume(6.20m^3)}\ ,(m^3/kgVS)$$

Where:

TS = total solids in slurry, %

VS = volatile solids for slurry, %

ρ = density of initial slurry, kg/m^3

2.5. The biogas composition and methane percentage

A portable biogas analyzer (Multi-gases detector, Shi'An Technology Instrument, China) was used to detect and analyze the biogas volumetrically with measuring error of ±1% and range of 0-100% (Vol.) for CH_4, 0-100% (Vol.) for CO_2 and 1-1000 ppm for H_2S, as illustrated in Fig.(2).

Fig.(2): The Biogas analyzer

2.6. The daily gained energy of biogas

Since the calorific value of methane equal to 37.78 MJ/m^3 **(Murphy and Thamsiriroj, 2013),** the daily gained energy of the biogas yield was estimated by using following relation:

$$\text{Daily gained energy of biogas (MJ/day)} = \text{biogas yield } (m^3/\text{day}) \times CH_4\,(\%) \times CH_4 \text{ Calorific Value } (MJ/m^3)$$

2.7. The developed digester versus the conventional digester

2.7.1. Construction works and time

The conventional rural biogas digesters used in Egypt the floating gas holder type that basically are consisted of often almost vertically cylindrical building of digester, gas holder, feeding and outlet chambers. The common method of the construction of these digesters needs to skilled labor, more of construction time and many building materials. The digester was built using bricks and mortar (mixture of cement, sand and water). The cylindrical gas holder is made from metal sheets and moves up and down to store and release the produced biogas. It is provided with internal metal beams to destruct the scum by periodic manual stirring of gas holder around its guide. The construction works, materials and time for the conventional digester compared to same volume developed digester can be depicted in Fig.(3) and Table (2).

(a) (b)

Fig.(3): The construction works for *a) the developed and b) the conventional digester.*

Table (2): Construction works and time for the conventional and developed digesters

Conventional digester construction time (Total volume= 9.16 m^3)*		Developed digester construction time (Total volume= 9.16 m^3)	
Construction works	**Construction time (days)**	**Construction works**	**Construction time (days)**
Excavation (Digging)	1	Excavation (Digging) - Pouring the digester's concrete bottom - Fixing the pre-constructed concrete digester, inlet and outlet pipes and gas holder beams and guide - composing the gas holder - Filling dusts - Building the feeding and outlet chambers	1
Pouring the digester's concrete bottom	1		
Building cylindrical brick digester and fixing the inlet and outlet pipes and gas holder beams and guide	7		
Lining	2		
Filling dusts after completed construction and composing the gas holder	1		
Building the feeding and outlet chambers	2		
Filling and operating the digester	1	Filling and operating the digester	1
Total construction time (days)	**15**	**Total construction time (days)**	**2**

The construction works and time table of the conventional digester in Table (2) is belonging to floating dome anaerobic digester that has been built at Abou Kabir district, Sharkia Governorate by Faculty of Agriculture under the supervision and implementation of* ***Tawfik M.A., Abd Allah W.E and Metwally K.A.*

From the previous table, it is clear that the developed digester saved about 86.67% of the construction time comparing to the conventional one.

2.7.2. Cost analysis of the conventional and developed digesters

The construction costs for the conventional and developed digesters with the same total volume (9.16 m^3) can be showed in Table (3) according to prices in year of 2018. The life cycle cost analysis was carried out for both conventional and developed digesters assuming useful life of 15 years according **(Arnoy *et al.*, 2014)**. The construction costs (fixed capital costs) (FCI) for construction of both conventional and developed digesters

Table (3): The construction costs of the conventional and developed digester according to the prices of 2018

Conventional digester construction cost*			Developed digester construction cost		
Construction materials	**Quantity**	**Cost in EGP (including transporting cost)**	**Construction materials**	**Quantity**	**Cost in EGP Including transporting cost)**
Bricks	3850	3500	Bricks	600	500
Cement	20 bags	1000	Cement	5 bags	250
Gravels	3 m^3	300	Gravels	3 m^3	300
Sand	4 m^3	300	Sand	1 m^3	75
Water	5 m^3	125	Water	2 m^3	50
Inlet and outlet PVC pipes 6 inches	6 m	450	Inlet and outlet PVC pipes 6 inches	6 m	450
Metal gas holder (diameter of 165 cm, height of 80 cm and thickness 2 mm)	1 piece	2500	Metal gas holder (diameter of 165 cm, height of 80 cm and thickness 2 mm)	1 piece	2500
Iron beams and guide of gas holder	1 piece	1200	Pre-constructed concrete digester including metal beams and guide of gas holder	1 piece	3000
Gas tap	1 piece	50	Gas tap	1 piece	50
Excavation & Filling works		**Cost (EGP)**	**Excavation & Filling works**		**Cost (EGP)**
Excavation Filling dusts after completed construction		1200 1000	Excavation and Filling dusts after completed construction in the same day		1200
Skilled labor		**Cost (EGP)**	**Skilled labor**		**Cost (EGP)**
Building labor		2000	Skilled building and concrete labor		500
lining labor		1000			
Pouring concrete labor		500			
Total cost (EGP)		**15125**	**Total cost (EGP)**		**8875**

According to the actual prices of the conventional anaerobic digester construction at Abou Kabir district, Sharkia Governorate that constructed under the supervision and implementation of* ***Tawfik M.A., Abd Allah W.E and Metwally K.A.*

according to 2018 prices. From Table (3), the developed construction of biogas digester contributed to minimize cost about of 41.32% than the conventional construction. But we can calculate the operating cost of anaerobic digestion operation using locally delivering costs of cattle manure including transporting cost (150 EGP/m^3). In this study, the annual total amounts of cattle manure slurry about 37.2 m^3 (hydraulic retention time of 60 days). The annual **O**perating labor and **M**aintenance and **R**epairs (OMR) costs were assumed to be 3000 EGP/year. The outlet effluent liquid (by-product) was assumed to be reused on the farm as biogas fertilizer at prices of 70 EGP/m3. Hence, cost per unit of generated biogas energy was calculated for the developed digesters by using the following equations given by **Chel *et al.*, (2009)**:

- Present OMR cost

$$\mathbf{P_{OMR} = C_{OMR}\left[\frac{\left((1+i)^{15}-1\right)}{\left(i\times(1+i)^{15}\right)}\right]}$$

Where:

C_{OMR}= Annual OMR cost, EGP

i = Interest rate (taken 17% according to Egyptian Central Bank in 2018).

- Net present cost

$$\mathbf{P_{Net} = P_{FCI} + P_{OMR} - \left[\frac{S}{(1+i)^{15}}\right] - \left[\frac{BF}{(1+i)^{15}}\right]}$$

Where:

P_{Net}= Net present cost, EGP

P_{FCI}= Fixed Capital Investment, EGP

BF= By-product value of Biogas Fertilizer at the end 15 years, EGP

S= Salvage value at the end 15 years (taken 15% of metal gas holder capital cost), EGP

- Annualized cost

$$\mathbf{A_A = P_{Net}\left[\frac{\left(i\times(1+i)^{15}\right)}{\left((1+i)^{15}-1\right)}\right]}$$

Where:

A_A=Annualized cost of system, EGP/Year

- Average Cost per unit of generated biogas energy

$$\mathbf{C = \frac{A_A}{U}}$$

Where:

C= Cost per unit of generated biogas energy by developed digester, EGP/MJ

U= Total annual gained biogas energy, MJ/year

In this study, the cost of the biogas energy unit was compared with the actual cost of other types of energy using Table (4).

Table (4): The actual price(not subsidized) of the energy unit for different energy sources

Energy Source	Actual price of energy, EGP	Calorific value ,MJ	Price of energy unit, EGP/MJ
Electricity	1.45 EGP/kWh	1 kWh = 3.6	0.403
Natural Gas	3.5 EGP/m^3	1 m^3 = 36.6	0.096
Liquid Petroleum Gas	175 EGP/Cylinder	*****1Cylin. (6.12 kg) = 278.66	0.628
Diesel fuel	8.2 EGP/L	1 L = 36	0.228
Gasoline 80	7.14 EGP/L	1 L = 32	0.223

**40% propane and 60% Butane*

RESULTS AND DISCUSSION

The obtained results will be discussed under the following topics:

1. The ambient and slurry temperature for developed digester at Lower and Upper Egypt

Obviously, the temperature is one of the most crucial factors affecting strongly the anaerobic biodegradation process rate and consequently the biogas yield. Due to the high costs of digester heating technologies, so this work investigated the performance of the developed digester without heating in winter season at two different regions of LoE and UoE during 60 days of batch anaerobic fermentation. The obtained data show that the average ambient and digestion temperatures were about 21.3^{o}C and 19.9^{o}C, respectively at LoE, while the average ambient digestion temperatures were about 30.1^{o}C and 28.8^{o}C, respectively at UoE. On One hand, the ambient temperature at UoE is higher than LoE with temperature range of 6 - 12 ^{o}C because the UoE is more temperate in winter season comparing to LoE. On the other hand, the difference in the digestion temperature at UoE is higher than LoE with temperature 6.30 - 11.7 ^{o}C, so it is obvious that a little difference between ambient temperature and digestion temperature was noted regardless the region of the experiment, as shown in Fig.(4).Hence, it is obvious that the digestion temperature of 19.9 ^{o}C at LoE allocated in psychrophilic range (<25 ^{o}C) and digestion temperature of 28.8 ^{o}C at UoE allocated in mesoophilic range (25-40 ^{o}C) according to **(Uzodimna *et al.*,2007)**. Accordingly, the biogas production at UoE expected to be higher than the LoE. It can be concluded that there is a strong influence of ambient temperature on the digestion temperature, particularly with the floating dome digester (KIVC model) due to the high heat conduction throughout the metal of gas holder (gas store).

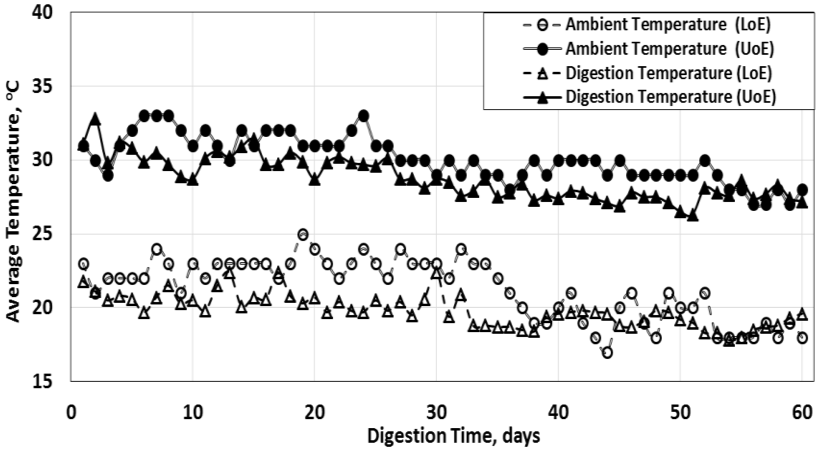


Fig. (4): Average daily variation of the ambient and slurry temperature for developed digester at Lower and Upper Egypt.

2. The pH values for the digested slurry within the developed digester

The low or high slurry pH and the low digestion temperature during the anaerobic fermentation create depressive environment for a methanogenic microbial consortia, resulting in inhibition of methanogensis by slowing down the metabolism of the mesophiles. The interactive between the pH of slurry and the digestion temperature is very important to understand the main reasons for the increment or the retardation of biogas yield. Generally, the methanogenic bacteria are in thrive optimally within the pH range of 6.4-7.4, particularly in the temperature of mesophilic range (25-40°C). Fig.(5) illustrate the fluctuation of the digested slurry pH values during the digestion period within the developed digester at the LoE and UoE. Regarding to the experiment at LoE, the obtained results showed that the pH values of the digested slurry drifted rapidly from neutral pH of 7.6 towards acidic pH of 6.06 during the initial phase of the digestion that extended from the filling day to the 9^{th} day, afterwards the pH values tends to increase apparently to the its peak value of 7.34 at the 44^{th} day and then the stabilization stage started until the end of digestion period. It is obvious that the drift of pH values to acidic range at LoE experiment referred to the accumulation of the free fatty acids and took more time than the pH value at UoE to reach the natural value. Concerning the experiment at UoE, pH value of the digested slurry decreased slightly from 7.90 to 6.84 at the 9th day then it fluctuated until reach the optimal pH of 7.00 at the 31th day. After that the pH value tends to increase gradually to reach 7.58 at the 51th day and continue to be stable around the neutral value until the end of the digestion period. The values of slurry pH within the developed digester either at LoE or UoE were increased from the acidic pH at fermentation start to the recommended range (around 7) at 20th day, and then it tends to be stable till the end of digestion. This because the slurry of cattle dung has sufficient buffering capacity producing alkalinity due to the degradation of substrates and this property helps to neutralize the accumulated acids and contribute to create ideal environment for the biodegradation process. Generally, it was observed that the average pH values during the digestion at LoE and UoE are very close, but the dramatic drop in pH value at LoE during the first 20 days of fermentation will reduce definitely the average biogas yield.

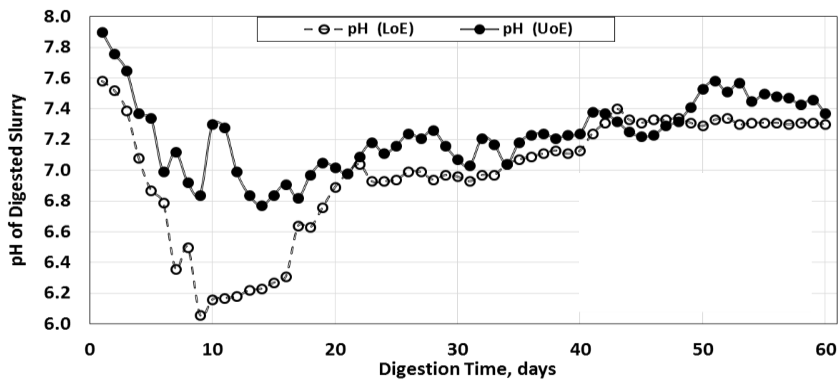


Fig.(5): The pH fluctuation of slurry within the developed digester at LoE and UoE.

3. Daily, cumulative and specific biogas yield for the developed digester at Lower and Upper Egypt

Based on there is no microbial starter in the two experiments as mentioned previously, the obtained data show that the biogas production started at the 5th day of fermentation with yield of 0.354 m^3 at UoE experiment, while the biogas production started at the 10^{th} day of fermentation with yield of 0.411 m^3 at LoE, as shown in Fig.(6-a).This lag in biogas production at LoE can be attributed to the inhibition effect of the psychrophilic temperature, whereas the temperate region of UoE helped in fast anaerobic fermentation. Fig.(6-a) depicts that the daily biogas yield increased at LoE and UoE to reach their peak values of 2.884m^3 at 19^{th} day and 2.410 m^3 at 21^{th} day, respectively. Afterwards, the biogas yield decreased slightly at UoE and rapidly at LoE till the end of digestion period, with note that the daily biogas yield at UoE maintained higher during the fermentation period extended from 22^{th} to 43^{th} day due to the good effect of the interaction between the pH and the digestion temperature on the methanogenic microbial consortia at UoE. Generally, the average daily biogas yield during the digestion period was about 0.986 and 1.649 m^3 for the LoE and UoE experiment, respectively. Regarding the cumulative biogas yield for 60 days of anaerobic digestion, Fig.(6-b) show that the cumulative yield of biogas yield increased with rapid rate during the two weeks extended from the 5^{th} and the 19^{th} for the UoE and with slow rate from the 10^{th} day to the 21^{th} for LoE experiment. Then the cumulative yield of biogas yield decreased slightly till the end of the two experiments. By the end of digestion period the cumulative yield of biogas yield for the LoE and UoE were 92.454 and 50.122 m^3, respectively.

In respect of the specific yield of biogas yield, the practical results show that the biogas yield from one kilogram of volatile solids (VS) of the cattle manure substrate was about 1.588 and 0.888 m^3 for the experiments at UoE and LoE, respectively, as depicted in Fig.(6-c). It is clear that, the using of the developed digester at UoE led to increase the average daily, cumulative and specific biogas yield with about 40.20, 45.78 and 44.08%, respectively higher than the LoE.

4. Composition of the produced biogas by the developed digester at Lower and Upper Egypt

Basically, the biogas is composed from two dominant gases namely; the methane (CH_4) and the carbon dioxide (CO_2) where the volumetric mixture of these gases may represents up to 99% of the biogas, whereas the rest constituted from hydrogen sulphide (H_2S), Ammonia (CH_3) and Hydrogen (H_2) as well as traces of other gases.

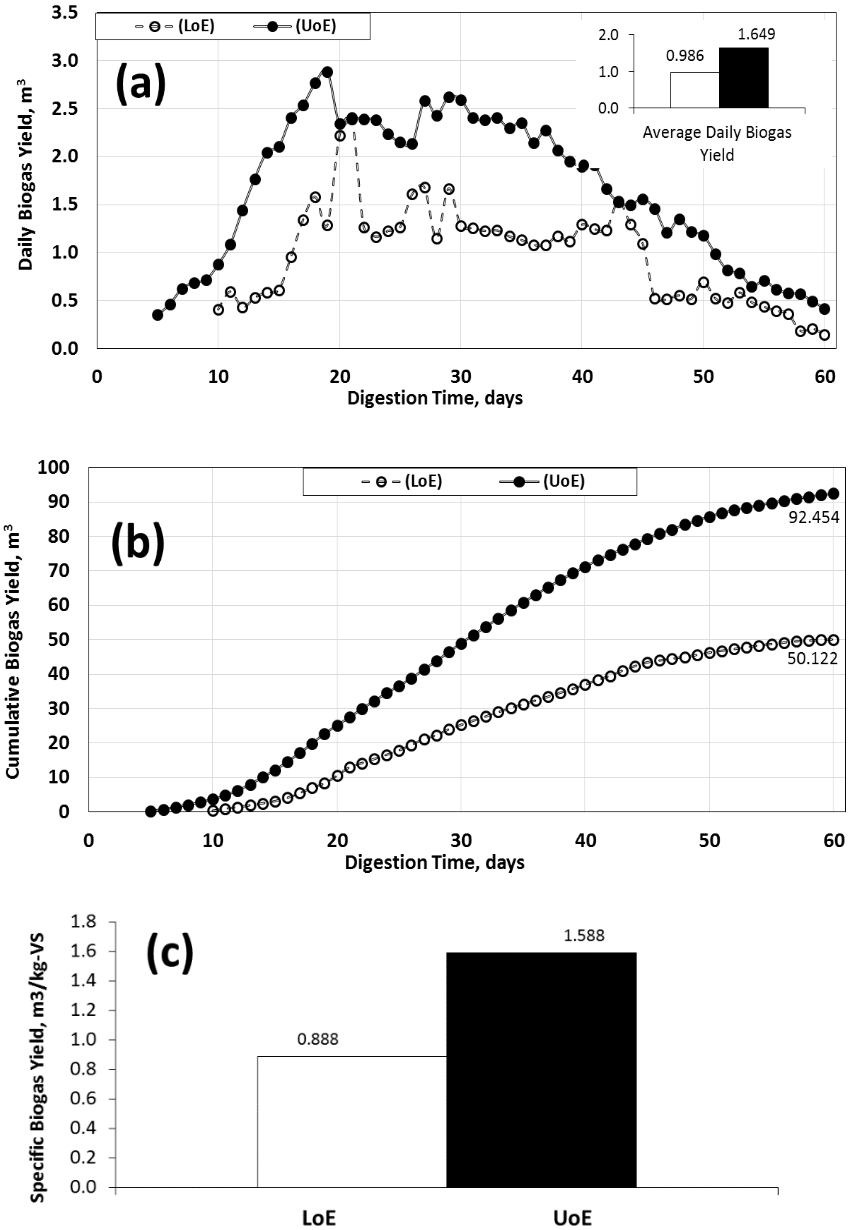


Fig. (6): Daily, cumulative and specific biogas yield for the developed at LoE and UoE.

Basically the quality of biogas yield mainly depends on the volumetric percentage of methane within the biogas mixture that reflects the capability of the anaerobic microbes to convert the VS to the desired bio-methane yield. Since the rich-biogas yield is desirable, the good digestion performance means the increase of the CH_4 content on the account of CO_2 and H_2S. The volumetric percentages of the CH_4 and CO_2 as well as H_2S in ppm were measured every day during the digestion period, as depicted in Fig.(7). Regarding the UoE experiment, the CH_4 percentage tends to decrease during the first three days, afterwards Ch_4 increased to its maximum content of 80% at the 23th day with CO_2 content of 20% and H_2S of 85 ppm, and then it tends to be stable at high methane percentage of 80% until the 37th then it declined gradually till end of digestion period. Concerning the LoE experiment, the CH_4 percentage tends to increase gradually from the 5th day till reaching its first peak content of 71% at the 22th day with CO_2 content of 29% and H_2S of 68 ppm, then it tends to decreased until the 29th day. The second CH_4 peak of 78% was recorded at the 45th day and tends to be stable at 70% during last week of the digestion period. It is obvious that the CH_4 content takes relative long time (about 20 days) to reach its second peak from 60 to 78% at LoE, as illustrated in Fig.(7).This can be referred to lag occurred in the methannogensis metabolism due to the negative effect of the psychrophilic temperature of the digested slurry, resulting in reduction in the biogas energy. Hence, the data indicated that digester at UoE gave the highest average of methane yield in biogas of 70.52% comparing to LoE (65.05%).

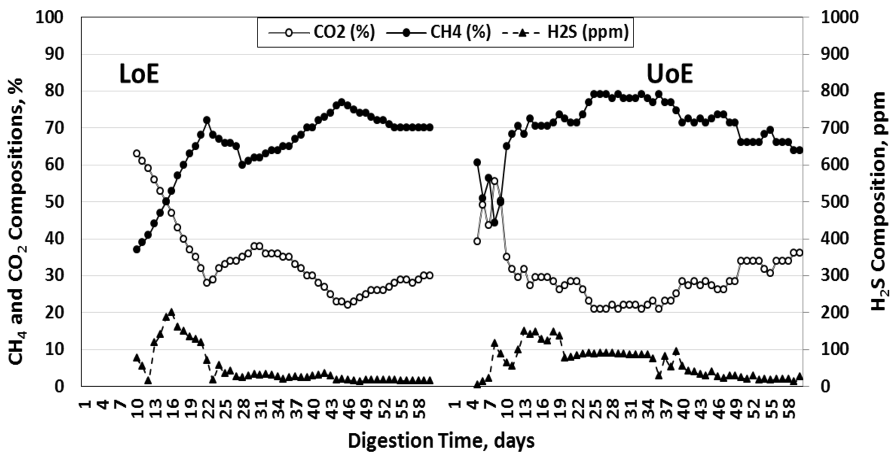


Fig.(7): The biogas composition of the developed digester at LoE and UoE.

5. Daily and total gained biogas energy using the developed digester at Lower and Upper Egypt

The volumetric percentage of CH_4 in biogas yield plays a vital role for determining the daily gained biogas energy and consequently the total gained energy during the digestion period. This means the calorific value of the biogas mainly depends on the methane yield. Fig.(8) display the daily and total gained biogas energy using the developed digester in LoE and UoE. The calculations indicated that, the maximum values of daily gained biogas energy using the developed digester at LoE and UoE were 6191.39 and 8000 MJ, respectively. However, the average daily gained biogas energy using the developed digester at LoE and UoE were 2431.64 and 4557.06 MJ, respectively. By the end of digestion period, the obtained data showed that the total gained biogas energy for LoE and UoE were 124013.8 and 255195.4 MJ, as demonstrated in Fig.(8). Based on the previous discussion, the obtained data indicated that the developed digester at UoE gave an increment in daily and total gained biogas energy with about 46.64% and 51.40 %, respectively higher than the developed digester at LoE.

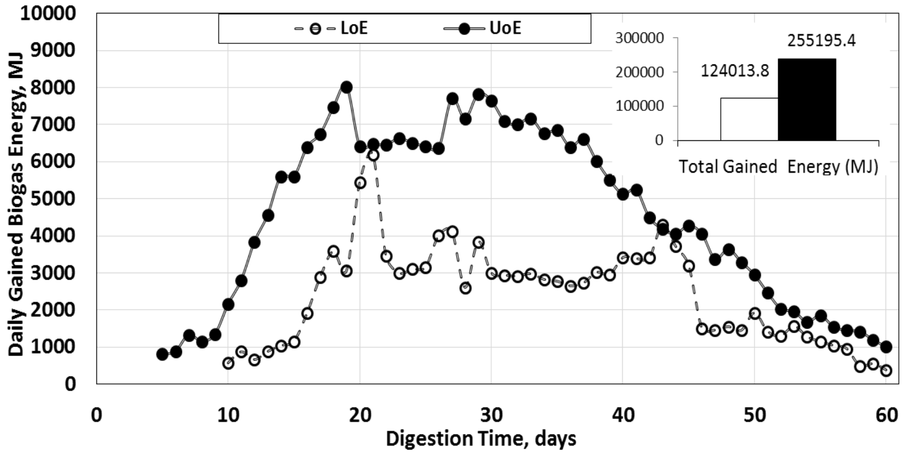


Fig.(8): Daily and total gained biogas energy for the developed digester at LoE and UoE

6. Criterion cost of biogas energy using developed digester at Lower and Upper Egypt comparing to other types of energy

According to practical work and calculations, the floating-dome developed digester with total volume of 9.15 m^3 was constructed within two working days either in LoE or UoE with total construction cost of 8875 EGP, while the conventional one with the same type and volume took 15 days and total construction cost of 15125 EGP. Obviously, the developed digester saved the construction time and total cost with about 86.67% and 41.32%, respectively comparing to the conventional digester, hence the potential of using the developed digester for producing biogas in Egypt deserve to be investigated. Based on the previous performance evaluation, the biogas energy criterion cost of the developed digester at UoE and LoE represented in the cost per biogas energy unit was calculated and compared to the cost per energy unit for different types of energy including the electric energy and fossil fuels taking into consideration the actual (not subsidized) prices in year of 2018, as illustrated in Fig.(9).The calculations revealed that the cost per biogas energy unit for the developed digester at LoE and UoE were 0.014 and 0.007 EGP/MJ. The natural gas has lowest criterion actual cost of 0.096 EGP/MJ, respectively comparing to the other conventional types of energy, as shown in Fig.(9). It can be observed that the developed digester at UoE and LoE have the lower cost than the actual cost of natural by about 85.41% and 92.7%, respectively. Ultimately, the developed floating–dome digester has good potential to produce reliable and economic rich-biogas yield in Egypt even in winter season comparing to the electric energy or fossil fuels, particularly at temperate regions such as UoE.

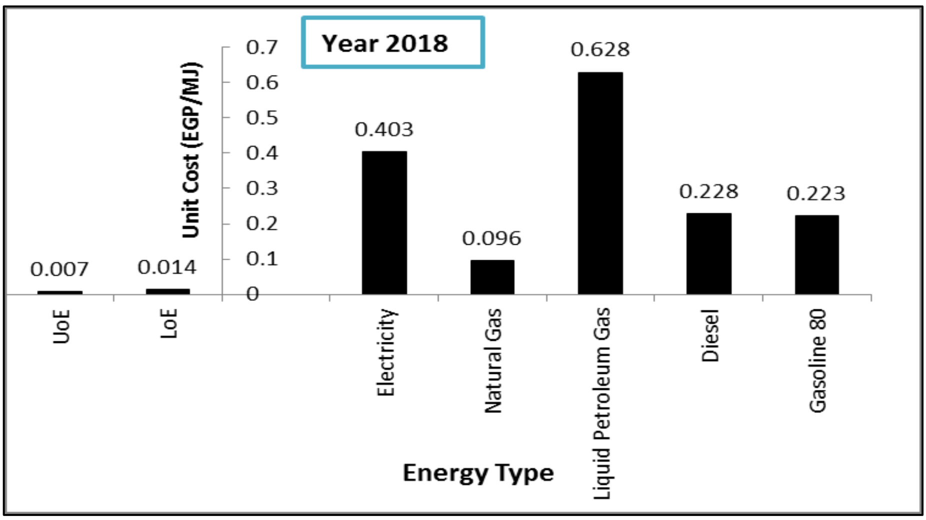


Fig.(9): Price of biogas energy unit using the developed digester at LoE and UoE comparing to actual prices (not subsidized) of energy unit for other energy sources.

CONCLUSION

This work demonstrated the developing of the construction of family-scale biogas digester using the floating-dome that considered the common design in Egypt in attempt to reduce the initial costs of construction comparing to the conventional digester. The performance of the developed digester (KIVC model) was evaluated during the winter season to investigate the potentiality of producing rich-biogas yield at LoE as relatively cold climate region and UoE as more temperate region. Additionally, the evaluation from the economic point of view was conducted to determine the cost of biogas energy unit comparing to the cost per energy unit of other conventional energy sources. The obtained results showed that using the developed digester at UoE gave higher values for daily, cumulative, specific biogas and methane yield comparing to the digester at LoE. Furthermore, the digester at UoE gave an increment in daily and total gained biogas energy with about 46.64 and 51.40 %, respectively higher than its counterpart at LoE. Generally, the developed digester reduces the construction time and total cost and gave the lowest cost per energy unit comparing to other conventional energy sources.

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الملخص العربي

جدوي إنتاج الغاز الحيوي بإستخدام هاضم لا هوائي مطور إنشائياً في شمال وصعيد مصر في موسم الشتاء

محمد علي توفيق[١] و وسام السيد عبد الله[٢]

تهتم هذة الدراسة بتطوير إنشاء هاضم لا هوائي ذو الخزان العائم من النوع العائلي لإنتاج الغاز الحيوي والذي يتمثل في إستخدام غرفة تخمير من الخرسانة سابقة التجهيز بدلاً من غرفة الهضم التي تبني من الطوب في الهاضم التقليدي وذلك في محاولة لتقليص زمن و تكاليف الإنشاء. كذلك تم تقييم أداء الهضم للهاضم المطور خلال فصل الشتاء لدراسة إمكانية إنتاج غاز حيوي غني بالميثان في شمال مصر وهي المنطقة الأبرد شتاءاً وصعيد مصر وهي تمثل المنطقة الأكثر إعتدالاً في الشتاء من خلال إنشاء هاضمين متطابقين من النوع المطور مع إستخدام روث الأبقار الحلابة.علاوة علي ذلك فإنه تم دراسة إقتصاديات الغاز الحيوي المنتج لتحديد تكلفة وحدة الطاقة للغاز الحيوي و مقارنتها بتكلفة وحدة الطاقة لأنواع أخري من مصادر الطاقة. أظهرت النتائج المتحصل عليها أن إستخدام الهاضم المطور في صعيد مصر أدي إلي زيادة متوسط إنتاج الغاز الحيوي اليومي(م^{٣}/يوم) و التراكمي (م^{٣}/٦٠يوم) و النوعي(م^{٣}/كجم مواد طيارة) عن مثيله في شمال مصر بنسب ٤٠,٢٠%، ٤٥,٧٨%، ٤٤,٠٨% علي الترتيب، مع زيادة ملحوظة للطاقة اليومية و الكلية المكتسبة من الغاز الحيوي بنسبة ٤٦,٦٤% و ٥١,٤٠% علي الترتيب، مع تحقيق أعلي قيمة نسبة متوسطة لغاز الميثان و هي ٧٠,٥٢% . من الناحية الأقتصادية فإن الهاضم المطور بشكل عام قلص زمن وتكاليف الإنشاء بنسبة ٨٦,٦٧% و ٤١,٣٢% علي الترتيب بالمقارنة بالهاضم التقليدي الذي له نفس التصميم و الحجم.إضافة إلي ذلك فإن تكلفة وحدة الطاقة لكل من الهاضم المطور في شمال وصعيد مصر كانت ٠,٠١٤ جنية/ميجاجول و ٠,٠٠٧ جنية/ميجاجول علي الترتيب و التي كانت أقل من تكلفة وحدة الطاقة الكلية (الغير مدعومة) للغاز الطبيعي (أقل تكلفة لوحدة الطاقة مقارنة بالطاقة الكهربية والبنزين والسولار والبتوجاز) بنسبة تصل إلي ٨٥,٤١% و ٩٢,٧% علي الترتيب. وأخيراً فمن الواضح أن الهاضم المطور له مستقبل جيد إقتصادياً وعلى مستوى الأداء وخاصة في المناطق المعتدلة مناخياً في فصل الشتاء مثل صعيد مصر.

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