STUDY THE EFFECT OF DRY FERMENTATION OF GOAT MANURE IN OPTIMIZATION OF BIOGAS PRODUCTION AND MINIMIZATION OF COSTS.

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ABSTRACT

In this study the effects of temperature, fermentation type and hydraulic retention time were investigated to optimize biogas yield and minimize production costs under lab scale for batch anaerobic digestion of goat manure. The growth and activity of anaerobic microorganisms is influenced by some parameters like temperature, moisture content, pH-value and volatile fatty acids (VFA), which were measured before the study. The methane values were between (61.89 – 69.35%). A cost equation was determined to calculate the total biogas cost LE/liter at different conditions. The minimum biogas production cost was 4.09 LE/liter at the highest cumulative production of 128.74 liter at temperature of 60 °C for dry fermentation.

Key words: *Goat Manure, dry fermentation, biogas, production cost.*

INTRODUCTION

The increase in production of organic wastes is considered one of the main environmental problems in Egypt, so that the sustainable waste management as well as waste prevention has become major political priorities, representing an important share of the common efforts to reduce pollution and greenhouse gas emissions and to decrease global climate changes. (Al Seadi et al. 2008).

Rashed (2014) reported that anaerobic digestion (AD) is the process of decomposition of organic matter by various types of anaerobic bacteria in the absence of oxygen to produce biogas in reactor tanks, commonly named digesters. A wide range of micro-organisms are involved in the anaerobic process to produce biogas and digestion product.

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Biogas is a combustible gas consisting of methane (CH4), carbon dioxide (CO2) and trace gases such as hydrogen and sulphide. Digestion product is the decomposed material, which is rich in macro and micro nutrients and therefore suitable to be used as plant fertilizer.

Field et al. (2008) reported that the use of agricultural waste as a source of renewable energy is suitable for improving energy security and decreasing environmental disruption caused by carbon emissions.

Angelidaki et al. (2003) reported that the growth and activity of anaerobic microorganisms is significantly influenced by temperature, pH-value, volatile fatty acids (VFA), ammonia and microelements. The anaerobic digestion (AD) process take place by different temperatures, divided into three ranges: psychrophilic bacteria (below 25Cº), mesophilic bacteria (25 – 45Cº), and thermophilic bacteria (45 – 70 Cº). The pH value of the organic matter influences the growth of methanogenic microorganisms and affects the dissolution of some compounds of importance for the AD process. The methane formation takes place within a relatively narrow pH interval, from about 5.5 to 8.5. The value of pH can be increased by ammonia, produced during degradation of proteins or by the presence of ammonia in the feed stream, while the accumulation of VFA decreases the pH-value. Microelements (trace elements) like iron, nickel, cobalt, selenium, molybdenum or tungsten are equally important for the growth and survival of the AD microorganisms as the macronutrients carbon, nitrogen, phosphor, and sulphur. The optimal ratio of the macronutrients carbon, nitrogen, phosphor, and sulphur (C:N:P:S) is considered 600:15:5:1. The hydraulic retention time (HRT) is an important parameter for economical biogas production. The HRT is the average time interval when the waste is kept inside the digester tank. The duplication rate of anaerobic bacteria is usually 10 days or more. A short HRT provides a good substrate flow rate, but a lower gas yield. It is therefore important to adapt the HRT to the specific decomposition rate of the used substrates.

 Borhan et al. (2012) fabricated a laboratory scale dry anaerobic digestion system to use with feedlot manure and inoculums mix at a ratio of 2:1 and was evaluated for a 40 day hydraulic retention time (HRT) under a 35±2˚C digestion temperature. The main constituents of biogas identified and

quantified were methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O). The average concentrations of CH_4 and CO_2 were 49%, and 44% respectively after 40 day.

This research was carried out to:

1- Optimize biogas yield from goat manure.

2- Minimize biogas production costs

3- Minimize hydraulic retention time.

MATERIALS AND METHODS

This research was carried out in the laboratory of Soil and Agricultural Engineering dept., Faculty of Agriculture Saba Basha, Alexandria University. The experiment was done to evaluate the effect of temperature, fermentation type and hydraulic retention time (HRT) as shown in Fig. (1). on the biogas production from goat manure on a laboratory digester to maximize gas production and minimize each of costs and hydraulic retention time. All experiments were done under batch system, which the wastes have been added once to the digester for whole duration of the process. The average batch weight for each digester was about 4 kg.

1-Materials:
1-1- Structure of the anaerobic digestion System
The anaerobic digesters consist of six glass bottles (5 liter) equipped with rubber stoppers, which produce biogas at temperature of 40, 60 C° and ambient temperature from goat manure for hydraulic retention time of 80 day. The digesters were placed in an isolated water bath, where the temperature was controlled by 1200W electric heater and thermostat. The digester rubber stopper is attached with a silicon tube to transfer biogas to plastic bottle (20 liter) filled with water at a specified level. The plastic bottle is attached with a silicon tube to transfer water to an empty plastic bottle (20 liter). The daily biogas production was recorded by measuring the collected water in the empty plastic bottle.

1-2- Goat manure (GM)
Goat population in Egypt is about 2.5 million head produce about 2400787.5 ton of wastes per year. Goat manure consists of undigested

residue of plant matter which has passed through the animal's gut. The resultant semi-decomposed organic matter rich in minerals and bacteria to break down organic matter and produce large amount of biogas. Goat manure is an excellent raw material for anaerobic digestion because of its high total nitrogen content and fermentation stability. The goat manure was obtained from a local farm. The goat manure was analyzed for chemical characteristic as shown in Table (1). The total solid (TS) for dry fermentation was 30% while was 10% for wet fermentation.
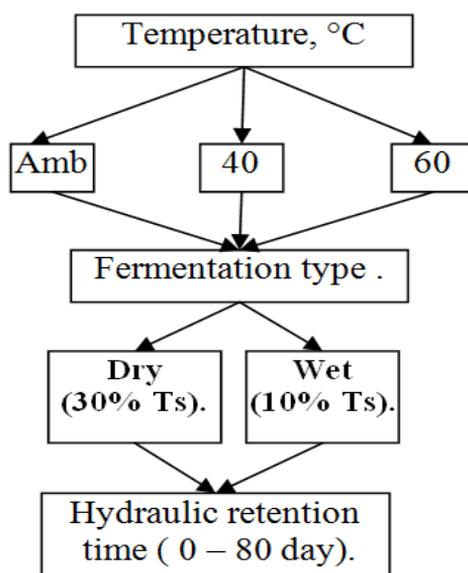

Fig.(1): Factors under study.

Table (1). Chemical characteristic for goat manure.

Characteristics	Goat manure
Moisture content (M.C), %	66.39 ± 3.12
Total solids (T.S), %	33.61 ± 3.12
Volatile solids (V.S), %	82.21 ± 8.93
Total organic carbon (T.C), %	18.22 ± 1.14
Total nitrogen (T.N), %	1.014 ± 0.11
Carbon / Nitrogen ratio (C/N ratio)	17.92 ± 0.81
pH	7.92 ± 0.14
potassium, % (K_2O)	3.2
phosphorus, % (P_2O_5)	0.53

2-Methodology:

Laboratory experiments were carried out to maximize biogas production from anaerobic digesters of goat manure. All laboratory experiments were done at pH from (6-8) and hydraulic retention time of 80 days.

2-1- Measurements:

A-The amount of water required to adjust the total solids of goat manure was calculated according to Lo *et al*. (1981) as follows:

$$D_w = R_m \left[\frac{TS_m - TS_d}{TS_d} \right]$$

Where:

D_W = water required, kg;

R_m = raw material weight, kg;

TS_m = total solid in raw materials; % and,

TS_d = total solids in fermentation materials, %.

B- The total solids (TS) of organic waste samples were determined by drying samples in oven at 105°c for 24 hours to calculate the weighed of the samples before and after drying. The total solids were calculated using the following equation according to (Peces, 2014).

$$Ts = \frac{Wd}{Ww} * 100$$

Where:

Ts: Total solids, %

Wd: Dry sample weight, gm

Ww: Wet sample weight, gm

C- The total volatile solids were determined from total solids using incineration oven at 600°C for 2 hours. The difference between the weights of the total solids and the ash gave the total volatile solids using the following equation according to (Peces, 2014).

$$T_{VS} = T_S - A_h$$

Where:

T_{v_s}: Total volatile solids, %

T_s: Total solids, % A_h : Ash, %.

D- Organic matter and organic carbon (O.M & O.C):

The percentage of organic matter was estimated from the percentage of ash at (550 - 600 °C) for 24 hours using the following equation according to (Peces, 2014).

Organic matter, % = 100 – ash, %

Organic carbon, % = $\frac{\text{Organic matter},\%}{1.724}$

Where 1.724 is Van Bemmelen factor.

E-The moisture content of waste samples were estimated by drying oven at 105 ± 1 °C for 24h (Suthar and Das, 1996). The desired moisture content for dry and wet fermentation was equipped by adding calculated amounts of distilled water to waste samples.

F- The pH is a hydrogen ion concentration in a solution, indicating its acidity or alkalinity. The pH meter (daigger 5500) was used to measure the pH values for goat manure with ranged from 6.00 to 20 with an accuracy of +/-0.01. The pH meter should be calibrated by using at least two buffers. (Ukpai and Nnabuchi, 2012)

G- The biogas composition was determined by biogas analyzer to measure the percentage of CH_4 (0-100%), CO_2 (0-100%), O_2 (0-25%), H_2 (0-1000ppm), NH_3 (0-1000ppm) and H_2S (0- 10,000ppm) in the biogas.
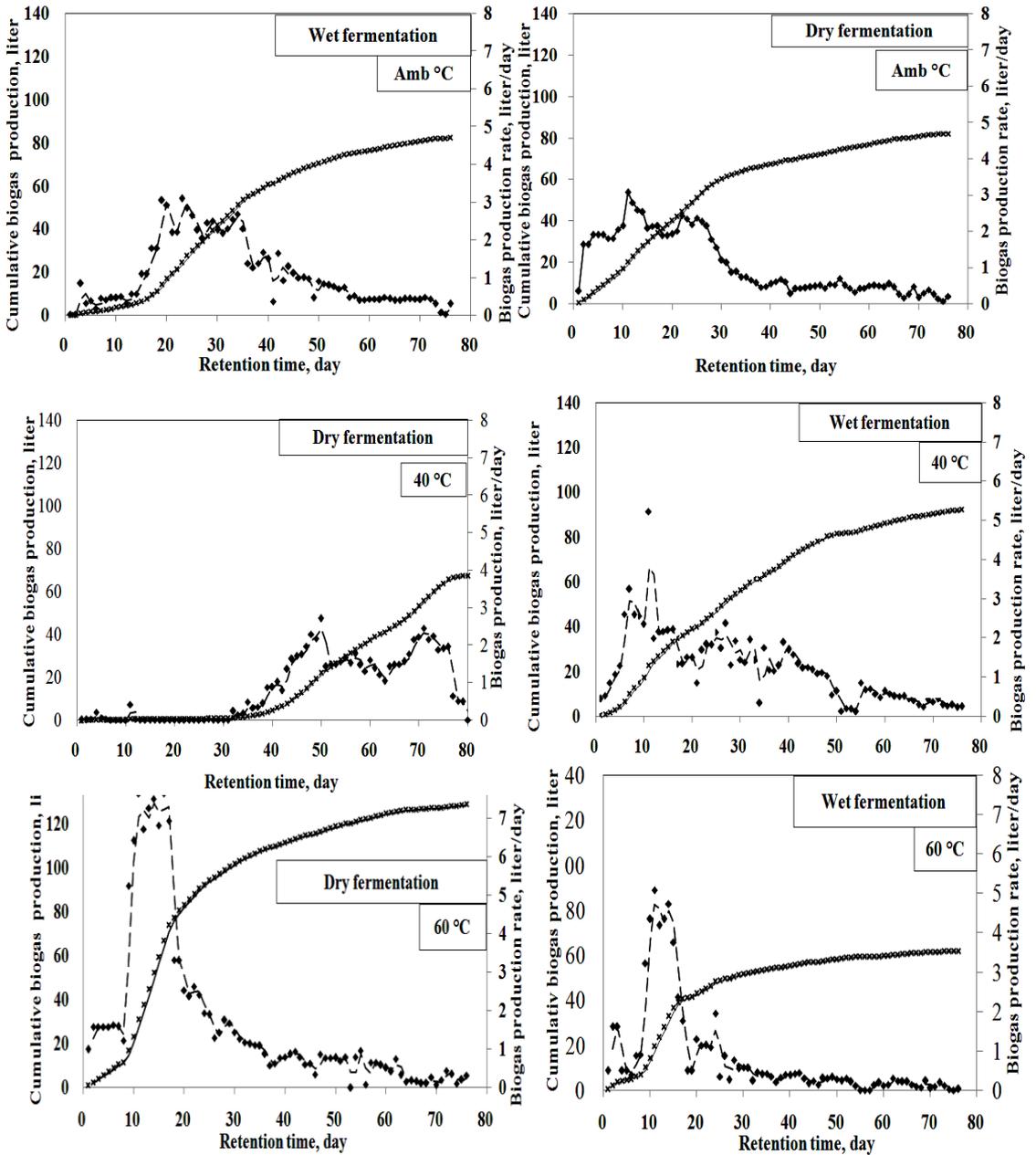
RESULTS AND DISCUSSION

1- Factors affecting biogas production

1-1 Hydraulic retention time (HRT):

Hydraulic retention time is the time that the waste spends in the digester. The relationships between daily and cumulative biogas production per liter and the time per day for dry and wet fermentation at temperatures of 40, 60 and ambient temperature C° are shown in Fig. (2). For all experiments the biogas production rate, liter/day was increased with the time until reached the maximum production value and then the biogas production was decreased until stopped.

It was observed that the highest biogas production rates by dry fermentation were 2.74 liter/day in the 50th day, 7.64 liter/day in the 11th day and 3.06 liter/day in the 11th day at temperature of 40, 60 and amb °C respectively, while were 5.23 liter/day in the 11th day , 5.07 liter/day in

the 11th day and 3.1 liter/day in the 23th day by wet fermentation at the above mention temperatures respectively.

× Cumulative biogas production, liter ◆ Biogas production, liter/day

Fig. (2). Daily and cumulative biogas production by dry and wet fermentation at temp of 40, 60 and ambient °C.

The cumulative biogas productions by dry fermentation were 58.95, 128.74 and 82.07 liter, while were 92.25, 61.72 and 82.56 liter by wet fermentation at temperature of 40, 60 and ambient temperature °C respectively. The highest cumulative biogas production was 128.74 liter by dry fermentation at temperature of 60 °C, while the lowest cumulative biogas production was 58.95 liter by dry fermentation at temperature of 40 °C.

1-2 Temperature:

The cumulative biogas productions by dry fermentation were 58.95, 128.74 and 82.07 liter, while were 92.25, 61.72 and 82.56 liter by wet fermentation at temperature of 40, 60 and ambient temperature °C respectively. The highest cumulative biogas production was 128.74 liter by dry fermentation at temperature of 60 °C, while the lowest cumulative biogas production was 58.95 liter by dry fermentation at temperature of 40 °C.

The temperature is an important factor affecting the growth, activity and survival of microorganisms. The effects of temperature on the cumulative biogas production for dry and wet fermentation are shown in Figs. (3 and 4). It was observed that the cumulative biogas production was increased with the time until reach the maximum values for all temperatures.

The highest cumulative biogas production by dry fermentation was 128.74 liter at temperature of 60 °C and followed by 82.07 liter at ambient temperature, while the lowest cumulative biogas production was 58.95 liter at temperature of 40 °C as shown in Fig. (3).

The highest cumulative biogas production by wet fermentation was 92.25 liter at temperature of 40 °C and followed by 82.56 liter at ambient temperature, while the lowest production was 61.72 liter at temperature of 60 °C as shown in Fig. (4).

The cumulative biogas production for wet fermentation at temperature of 40°C was higher than 60°C, because Mesophiles bacteria produces biogas for about 50 day with medium digestion rate, while thermophiles bacteria at 60°C produces biogas for about 30 day with high digestion rate. So the thermophilic conditions require less retention time and produce less amount of biogas than mesophilic condition at wet fermentation.
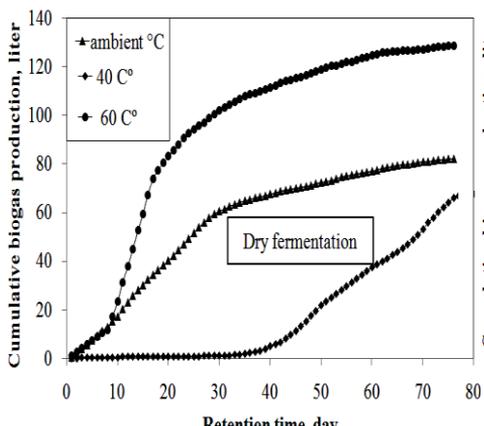
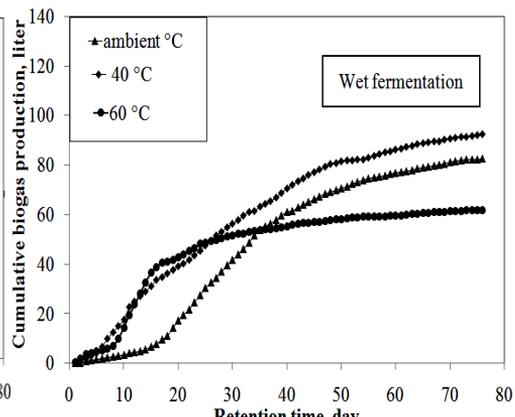**Fig. (3). Effect of temperature on the cumulative biogas production by dry fermentation.**

Fig. (4). Effect of temperature on the cumulative biogas production by wet fermentation.

The cumulative biogas production for dry fermentation at temperature of 60°C was higher than 40°C, because the Mesophiles bacteria produces biogas for about 40 day with medium digestion rate, while the thermophiles bacteria produces biogas for about 40 day at 60°C with high digestion rate. So the thermophilic conditions produces higher amount of biogas than mesophilic condition at dry fermentation, these results are consistent with (Rashed 2014).

At ambient temperature the cumulative biogas production by dry and wet fermentation take the same trend.

1-3 Fermentation type:

The effect of fermentation type on the cumulative biogas production at the above mention temperatures are shown in Figs. (5, 6 and 7). It was observed that the cumulative biogas production was increased with the time until reach the maximum values for dry and wet fermentation.

The cumulative biogas production by dry fermentation was higher than wet fermentation at temperature of 60 °C, which due to the total solids of dry fermentation was 30% of the total waste sample about 1.2 kg of 4 kg sample, while at wet fermentation the total solids was 10% of the total waste sample about 0.40 kg of 4 kg sample, so that the production of biogas by dry fermentation was higher than wet fermentation because the total solids at dry fermentation sample was higher than in wet fermentation by about 3 times and the activity of thermophiles bacteria is better at dry fermentation to convert organic matter into biogas.
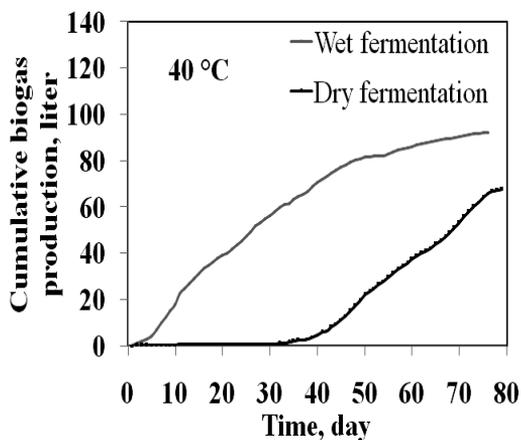
Fig. (5). Cumulative biogas production by dry and wet fermentation at temp. of 40 °C.
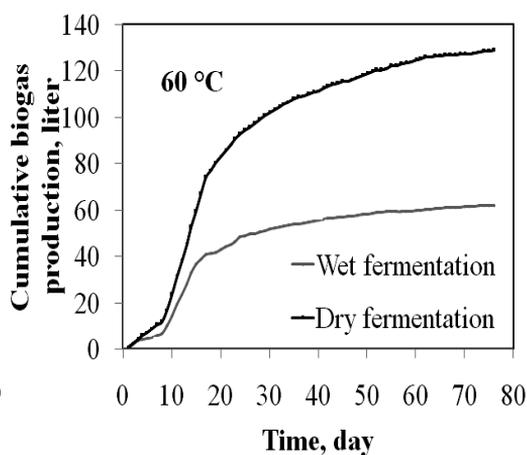

Fig. (6). Cumulative biogas production by dry and wet fermentation at temp. of 60 °C.
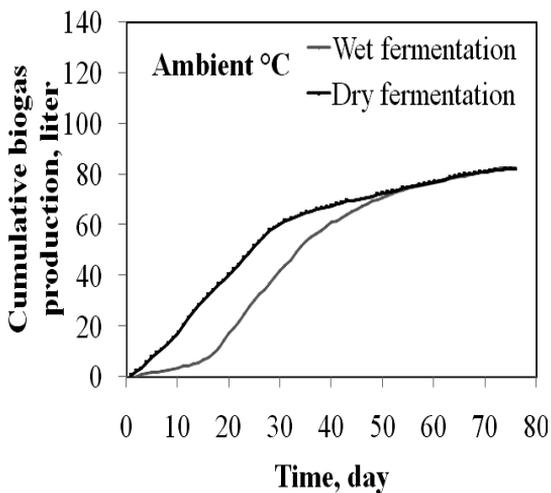

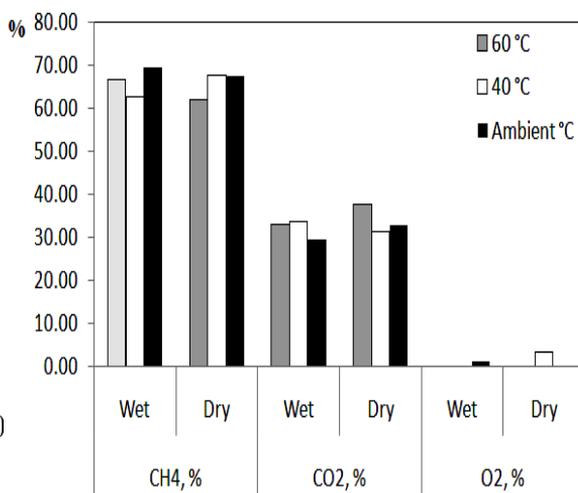**Fig. (7). Cumulative biogas production by dry and wet fermentation at ambient temp. °C.**

Fig. (8). Average biogas constituents by dry and wet fermentation at temp. of 40, 60 and amb °C.

At temperature of 40 °C the cumulative biogas production by wet fermentation was higher than dry fermentation, which due to the activity of mesophiles bacteria at wet fermentation is better than dry fermentation these results are consistent with (Rashed 2014).

At ambient temperature the cumulative biogas production by dry and wet fermentation take the same trend.

2- Biogas constituents

The biogas is a mixture of methane CH_4 (50–75%), carbon dioxide CO_2 (25–50), nitrogen N_2 (0–10), hydrogen H_2 (0–1%), Hydrogen sulfide H_2S (0–3%) and oxygen O_2 (0–3%). The methane is the most important element in biogas mixture because it is flammable and can be use as a fuel. The composition of biogas varies depending upon the anaerobic digestion process, to ensure optimum operation of the biological process and achieve the maximum methane yield, a biogas composition must be continuously monitored temperature, pH, hydraulic retention time, C:N ratio, volatile fatty acids, trace gases and the addition of substrate. The average biogas constituents for goat manure are shown in Table (2) and Fig.(8). The methane average values were between (61.89 – 69.35%).

Table (2). Average biogas constituents.

Temp, °C	CH4, %		CO2, %		O2, %	
	Wet	Dry	Wet	Dry	Wet	Dry
60	66.67	61.89	33.13	37.90	0.20	0.18
40	62.27	67.67	33.92	31.625	0.23	3.5
Ambient	69.35	67.23	29.35	32.617	1.23	0.18

3-Biogas production costs analysis

3-1- Construction costs of biogas system:

The laboratory biogas production system consists of six glass bottles (5 liter), 12 rubber stoppers, isolated water bath, electric heater with thermostat 1200W, 20 meter silicon tube and 12 plastic bottles (20 liter). The total construction cost for each laboratory digester was LE 175, while the total cost for six digesters was LE 1050. The total volume of the six laboratory digester is 30 liter, so it is too small to produce biogas economically; also the construction cost of laboratory digester is too high.

3-2- Raw material cost:

The cost of raw material is considered the most important factor which affects biogas price. The price of edible crops like wheat and corn are too high to produce biogas, on the other hand using these crops in biogas production increase food prices. Goat manure is a good source for biogas production because it is available semi-decomposed organic matter rich in bacteria, non edible and clean energy source. According to the local

prices the average cost of collecting and transportation 1024 kg of goat manure is about LE 80 ($ 4.7). The laboratory digester needs about 4 kg wastes with cost of LE 0.31.

The biogas production digester should be built inside animal farms to minimize collecting and transportation cost for economically biogas production.

3-3-Heating cost:

An electric heater was used to heat the water bath, where the temperature was fixed on 40 or 60 °C by thermostat. The electric energy consumption for heating one digester was about 1.63, 1.84 and zero kW.h per day at temperature of 40, 60 and Amp °C respectively, which was measured by digital multi-meter. The electric energy cost for heating one digester was about 0.40, 0.46 and zero LE per day at temperature of 40, 60 and Amp °C respectively.

3-4 - Workers cost:

The laboratory biogas production needs one technician to control biogas production stages such as, heating and gas transfer between units, the workers cost was about LE 50 ($ 3.12) per day for six digesters.

Table (3). Biogas production costs.

Temp, °C	Hydraulic retention time		Cumulative production, liter		Construction costs	Worker cost LE/day	Electric cost LE/day	Total biogas cost LE/liter	
	Dry fer	Wet fer	Dry fer	Wet fer	LE / digester			Dry fer	Wet fer
40	80	50	58.95	92.25	175.31	8.33	0.407	14.83	6.64
60	40	30	128.74	61.72	175.31	8.33	0.46	4.09	7.11
amb	40	50	82.07	82.56	175.31	8.33	0	6.20	7.17

3-5-Total biogas production costs:

The total biogas production cost consists of construction cost, worker cost, electricity cost and row material cost as shown in table (3).

A cost equation was determined to calculate the total biogas production cost.

$$T_{bc} = \frac{Cc + (Woc * Hrt) + (Elc * Hrt) + (Wac * \frac{Hrt}{40})}{Bip}$$

Where:

T_{bc} is total biogas cost, LE/liter

Cc is construction cost of biogas system, LE

W_{oc} is worker cost, LE/day

H_{rt} is hydraulic retention time, day

E_{lc} is electricity cost, LE/day

W_{ac} is raw material cost every 40 days, LE

B_{ip} is biogas production volume, liter

It was observed that increasing hydraulic retention time resulted in increasing worker cost, electricity cost and the total biogas production costs as shown in Table (3)., so it is important to minimize hydraulic retention time and maximize cumulative biogas yield to minimize the total costs. The total biogas production costs for dry fermentation was 14.38, 4.09 and 6.2 LE/liter at temperature of 40, 60 and ambient temp °C respectively, while was 6.64, 7.11 and 7.17 LE/liter for wet fermentation at the above mention temperatures respectively.

The minimum total biogas production cost was 4.09 LE/liter at the highest cumulative production of 128.74 liter which equal 25 times of digester volume (5 liter) at temperature of 60 °C for dry fermentation.

3-6-The recommended biogas unit for minimize costs

In order to minimize biogas production costs a local commercial digester (٣ m^3) equipped with a solar heater can be use to control the digester temperature. The construction cost of this system is LE 12000 with shelf life of 10 years. The produced gas volume is about 25 time digester volume every 40 days at dry fermentation of goat manure at temperature of 60 °C. Through ten years the digester produces about 6825 m^3 of biogas, which suitable for small family (4 people) the average biogas consumption for one person is about 0.4m^3/day.

The total biogas production cost can be reduced to 0.029 LE/liter by using this recommended digester.

4. CONCLUSIONS

The highest cumulative biogas production was 128.74 liter by dry fermentation at temperature of 60 °C, while the lowest cumulative biogas production was 58.95 liter by dry fermentation at temperature of 40 °C. The average methane production were between (61.89 – 69.35%) for all treatments. The total biogas production costs for dry fermentation was 14.38, 4.09 and 6.2 LE/liter at temperature of 40, 60 and ambient temp °C

respectively, while was 6.64, 7.11 and 7.17 LE/liter for wet fermentation at the above mention temperatures respectively.

The lowest biogas production cost was 4.09 LE/liter at the highest cumulative biogas production of 128.74 liter at temperature of 60 °C for dry fermentation. It is recommended to use a local digester (3 m^3) with solar heater to produce about 6825 m^3 of biogas in 10 years and minimize total biogas production cost to 0.029 LE/liter.

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الملخص العربي

دراسة تأثير استخدام التخمر الجاف لمخلفات الماعز في تعظيم إنتاج الغاز الحيوي وتقليل التكاليف

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تعتبر مصر هي أكبر منتج للنفط خارج منظمة أوبك وثاني أكبر منتج للغاز الطبيعي في أفريقيا. ومع ذلك، فإن إنتاج الطاقة في مصر قد تراجع بشكل مطرد منذ عام ٢٠٠٩ وفي عام ٢٠١٢. ويرجع ذلك إلى النقص في إنتاج الغاز الطبيعي و النفط. وقد أدى هذا النقص إلى انقطاع الكهرباء المتكرر بالأضافة الي وجود مشكلة تراكم للنفايات بجميع انواعها و التي من الممكن إستخدامها في إنتاج الغاز الحيوي و ذلك للحد من التلوث و الاحتباس الحراري والتخفيف من التغيرات المناخية العالمية. و يهدف هذا البحث إلى: ١- تعظيم إنتاج الغاز الحيوي من مخلفات الماعز. ٢- خفض تكاليف انتاج الغاز الحيوي. ٣- تقليل الفترة الزمنية لأنتاج الغاز بأستخدام التخمر الجاف. تم دراسة تأثير كل من درجة الحرارة والفترة الزمنية للتخمر الجاف و الرطب اللاهوائي لمخلفات الماعز علي كل من انتاج الغاز الحيوي و التكاليف الكلية لأنتاج الغاز في نطاق معملي. وكان أعلى إنتاج تراكمي للغاز الحيوي ١٢٨,٧٤ لتر باستخدام التخمر الجاف علي درجة حرارة ٦٠ درجة مئوية، في حين كان أقل إنتاج ٥٨,٩٥ لتر علي درجة حرارة ٤٠ درجة مئوية باستخدام التخمر الجاف . ولقد وجد أن الأنتاج الأقتصادي للغاز الحيوي لإنتاج ٨٥٪ من إجمالي إنتاج الغاز الحيوي التراكمي تم خلال ٤٠ يوماً للتخمر الجاف لجميع درجات الحرارة تحت الدراسة في حين تم الأنتاج خلال ٥٠ يوماً علي درجة حرارة ٤٠ مئوية و ٣٠ يوماً علي درجة حرارة ٦٠ مئوية و ٤٠ يوماً علي درجة حرارة الجو المحيط. وبلغ متوسط نسبة غاز الميثان في الغاز الحيوي المنتج ما بين (٦١,٩ – ٦٧,٦) لجميع المعاملات.

١ – مدرس الهندسة الزراعية – قسم الأراضي و الكيمياء الزراعية – كلية الزراعة ساباباشا – جامعة الأسكندرية.

٢– مدرس– قسم الهندسة الزراعية، كلية الزراعة الشاطبي ، جامعة الأسكندرية، مصر .

وبلغ أجمالي تكاليف إنتاج الغاز الحيوي للتخمر الجاف لروث الماعز ١٤,٣٨ و ٤,٠٩ و ٦,٢ جنيه / لتر علي درجات الحرارة التالية ٤٠ درجة مئوية و ٦٠ درجة مئوية و درجة الحرارة الجو المحيط على التوالي، في حين كانت ٦,٦٤ و ٧,١١ و ٧,١٧ جنيه / لتر للتخمر الرطب علي درجات الحرارة السابق ذكرها على التوالي. وبلغت أقل تكاليف لأنتاج الغاز الحيوي ٤,٠٩ جنيه / لتر عند أعلى إنتاج للغاز الحيوي التراكمي ١٢٨,٧٤ لتر بأستخدام التخمر الجاف علي درجة حرارة ٦٠ درجة مئوية.

يمكن خفض تكاليف إنتاج الغاز الي ٠,٠٢٩ جنيه / لتر من خلال إستخدام التخمر الجاف علي درجة حرارة ٦٠ درجة مئوية لمخمر محلي الصنع ذو حجم ثلاثة متر مكعب حيث تبلغ تكلفة البناء ١٢٠٠٠ جنية و ذلك للأنتاج ٦٨٢٥ متر مكعب بيوجاز خلال فترة زمنية مقدارها عشرة سنوات حيث تكفي هذة الكمية لأسرة مكونة من أربعة أشخاص لمدة عشر سنوات .