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DETERMINATION OF METHANE CONTENT BY MEASUREMENTS OF FLAME TEMPERATURE AND VOLTAGE FROM BIOGAS BURNER

Abdel-Hadi, M. A.[*]

ABSTRACT

This study presents the results of an experimental investigation of the flame temperature and voltage of biogas burner as a method to determine methane content in biogas. An experimental prototype has been developed to find the quality of biogas, which produced from mixture of cattle dung and chicken manure 50:50 %, total solid (7.8 % TS) by bench-scale continues anaerobic digester (horizontal type) with 17 liters digestion volume and 25 days hydraulic retention time (HRT). The hydraulic retention time was replicated two times under 38 °C mesophilic region in order to reach the steady state biogas product.

The obtained results showed that, the minimum flame temperature and voltage were 460 °C and 38 mV, respectively at 54.5 % methane. Meanwhile, the maximum flame temperature and voltage were 631 °C and 42.6 mV, respectively at 68.1 % methane. The average velocity of biogas passing through the port of burner (3 mm diameter) was 2.1 m/s and the average biogas pressure in gasholder was 996 mbar. The biogas flow rate through the port of burner was 0.9 liter/min and laminar, flow type.

The variation of flame temperature and voltage of the sample of biogas collected from a bench-scale anaerobic digester every day was also studied to find the change in quality throughout the second replicate hydraulic retention time. The obtained data indicated that, there was a proportional relationship between flame temperature, voltage and methane percentage in the biogas.

Keyword: *Biogas; Methane content; Flame temperature; Biogas pressure; Reynolds number*

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[*] Assist. Prof. of Agric. Eng. Dept., Fac. of Agric., Suez-Canal Univ., 41522 Ismailia, Egypt.

INTRODUCTION

Energy is considered a prime agent in the generation of wealth and a significant factor in economic development. The importance of energy in economic development is recognized universally and historical data verify that there is a strong relationship between the availability of energy and economic activity. Although at the early 70_s, after the oil crisis, the concern was on the cost of energy, during the past two decades, the risk and reality of environmental degradation have become more apparent. Achieving solutions to environmental problems that humanity faces today requires long-term potential actions for sustainable development. In this respect, renewably energy recourses appear to be one of the most efficient and effective solution. Biogas is one of the most important renewable energy recourse. Biogas is a mixture of colourless flammable gases obtained by the anaerobic digestion of plants -based organic waste material **(Abubakar, 1990 and Maishanu *et al.*, 1990)**. Biogas is also obtained by fermentation of organic materials such as animal, human, agricultural and industrial wastes **(Cheremisinoff and Ellerbusch, 1980)**. The use of biogas as an energy source has numerous applications. However, all of the possible applications require knowledge about the composition and quantity of constituents of the biogas. The percentage of methane in the biogas is generally determined by the Orsat apparatus, gas-chromatograph etc. **(Holman, 1995)** these are not absolutely required.

The quality of biogas depends mainly on its presence of methane. A good quality biogas has high caloric value and burns in air with a blue flame. This is due to its presence of a high percentage of methane **(Mandal *et al.*, 1999)**. The quality of biogas generated by waste materials does not remain constant but varies with the period of digestion **(Khandewal and Mahdi, 1986)**. The methanogenic activity is more likely to proceed optimally in a narrow pH value range, between 6.3 and 7.8 **(Van Haandel, 1994; Van Haandel and Lettinga, 1994)**. Methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6.5. As the digestion process continues, concentration of NH_4 increases due to digestion of nitrogen which can increase the pH value to above 8. When the methane production level is stabilized, the pH range remains buffered between 7.2 to 8.2 **(FAO, 1997)**. **Constant *et al*. (1989)** reported that the biogas at a constant concentration of 60 % CH_4 (methane) and 40 % CO_2, is flammable when its concentration in air is between 8.83 and 20 % vol. and it will not burn using a conventional combustor if its CO_2 concentration is more than 75 %. Biogas is about 20 % lighter than air and has an ignition temperature in the range of 650 – 750 °C. It is an odourless and colourless gas that burns with clear blue flame **(Sathianathan, 1975)**. Biogas is somewhat lighter than air and has an ignition temperature of approximately 700 °C **(Kohler, 2007)**. **Werner *et al*. (1989)** reported that the ignition temperature for biogas (65 % CH_4, 34 % CO_2 and 1 % rest) is 650-750 °C. Meanwhile, the temperature of the flame is 870 °C **(Sasse, 1988)**. The flame is generally considered of two regions, referred to as preheat and reaction zones. The reaction zone is further divided into two parts, the primary and secondary reaction zones. The primary zone is approximately coincident with the luminous zone, while the secondary zone is associated with an area of weak secondary luminosity due to CO oxidation **(Rallis and Garforth, 1980)**.

The flame temperature of the fuel is proportional to its caloric value and the quality of the fuel **(Shah, 1974)**. Hence, the flame temperature of biogas indicates its quality, i.e. the percentage of methane in it. The temperature can be obtained from any of the spectroscopic methods by comparing line intensity as a function of energy level. The most direct technique for temperature measurement is the use of small thermocouples. Thermocouples are a widely used electric output device for obtaining temperature measurements during experimentation **(Wheeler and Ganji, 2004; Kreith, 2000 and Bolton, 2003)**.

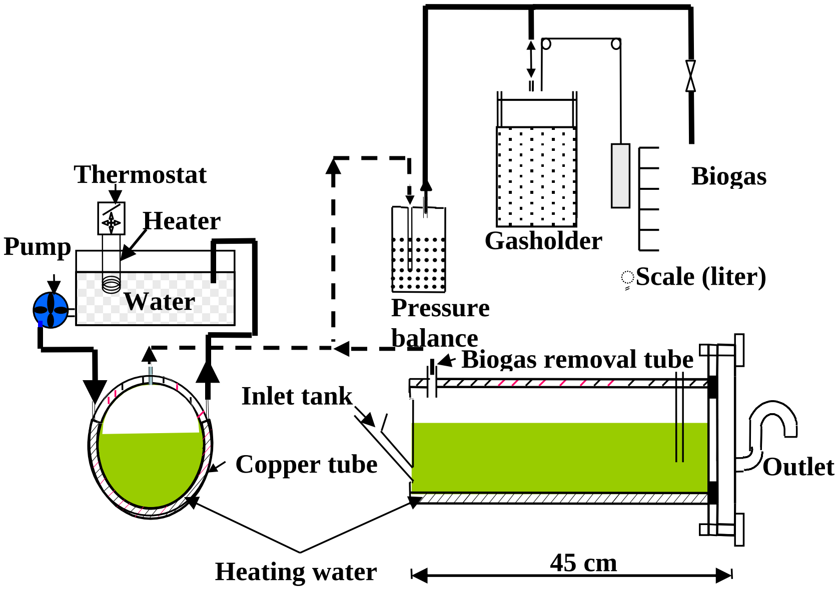
The gas holder delivers pressure enough to operate gas burner and co-generation motor without any compressor to raise pressure **(CAEEDAC, 1999)**. The low-pressure, wet and dry gasholders is (10-50 mbar) basically, these gasholders are identical to integrated and/or plastic (sheet) gasholders. Meanwhile the medium- or high-pressure gasholders is 8-10 bar to 200 bar **(Werner *et al*., 1989)**. The burning velocity depends on the thermal diffusivity, average reaction rate, initial fuel concentration, flame temperature, ignition temperature and initial temperature of the reactants **(Borman and Ragland, 1998**). Taking these calculations into considerations, it was revealed that the burning velocity should be approximately 0.22 m/s. Other texts suggest a burning velocity of between 0.25 m/s and 0.34 m/s **(Fulford, 1988**). **Leung and Wierzba (2008)** found that for the biogas mixture of 60 % methane and 40 % carbon dioxide no flame could be stabilized on nozzles with diameter less than 2.8 mm. **Accutherm International Pty Ltd. (2001)** reported that, if Reynolds number > 2320 the flow type is defined as turbulent. Meanwhile, **Trigas (2002)** mentioned that, the transition from laminar to turbulent flow generally occurs at a Reynolds number ranged between 2000 and 4000. Reynolds numbers higher than 5000 are indicative of turbulent flow.

In this paper, an attempt has been made to present the results for experiments conducted to determining the quality of biogas (methane %) produced from mixture of cattle dung and chicken manure 50:50 % TS during its digestion period. The measurement of physical properties of the biogas burning such as flame temperature and voltage was also carried out.

MATERIALS AND METHODS

1. Bench-scale Biogas Digester

A bench-scale of cylindrical biogas digester (horizontal type) as shown in Fig. (1) was constructed at the workshop of Agricultural Engineering Department, Faculty of Agriculture, Suez-Canal University. The digester was fabricated from galvanized steel sheet of 1.5 mm thick, 450 mm long and 250 mm diameter with total capacity of 22 liters and actual digestion volume of 17 liters. For feeding the organic wastes and rejecting the digested materials, PVC inlet and outlet tubes of 50.8 mm (2 in.) diameter were fixed to the digester. To follow up the digestion processes, the digester was equipped by two orifices; one for releasing the produced gas and the other for the pH-temperatures measurements. Released gas volume was collected in gasholder and determined.



A: Digester cross section B: Digester longitudinal section

Fig. (1): Schematic diagram of the horizontal bench-scale biogas digester.

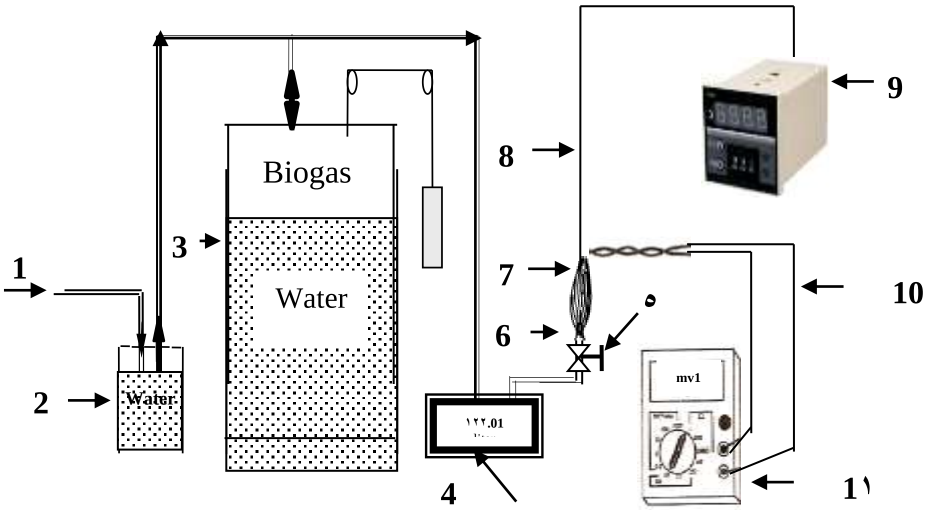
The bench-scale digester was used to measure and detect the suitable operating conditions to obtain the maximum possible biogas production with high methane percentage at used mixture 7.8 % TS of cattle dung and chicken manure (50:50 % TS). A thermostatic heating unit was connected to the digester with a pump in order to adjust the temperature of the digester. The temperature of mixture inside digester was adjusted within the mesophilic process (38 °C). The retention time of 25 days was used and replicated two times through the experimental work in order to reach the steady state biogas product. Meanwhile the input digested material of mixture was 0.680 liter/ day.

The biogas burner (8 mm and 3 mm outer and port diameter) fabricated from steel was feted to the biogas holder as shown in Fig. (2).

2. Analytical Methods and Instrumentation

2.1. Daily biogas volume yield

During the continues fermentation, the released gas volume in liter per day was measured laboratory using the wetted displacement with a previously calibrated scale as shown in Fig. (1).



1- Inlet biogas (from digester)
2- Pressure balance chamber
3- Gasholder
4- Gas meter
5- Control valve
6- Burner
7- Biogas flame
8- Thermocouple (J type)
9- Digital Temperature Controller
10-Thermocouple (K type)
11- Digital multimeter

Fig. (2): Schematic diagram of the experimental setup for temperature and voltage measurements of biogas flame.

2.2. Methane percentage

The percentage of methane content in each sample was determined using a gas chromatography GC (Chrompack CP 9001) at a flow rate of 18 ml/min with helium as a carrier gas. The flame-ionization-detector (FID) was operated at a flow rate of H_2 24 ml/ min and make up N_2 of 30 ml/min.

2.3. pH meter

The pH value of the mixture (cattle dung and chicken manure) solution inside the bench-scale digester was regularly daily measured using Jenway pH hand held meter model 370 pH/mV.

2.4. Biogas pressure, velocity and Reynolds number

The velocity of biogas inside the port of burner was measured by water tube manometer **(El-Awady and El-Said, 1989)** and also the biogas pressure in gasholder as shown in Fig. (3). The average velocity and biogas pressure were 2.1 m/s and 996 mbar, respectively, meanwhile the

Reynolds number was 610. The following equations were used to calculate the biogas velocity, pressure and Reynolds number:

$$V = \sqrt{0.2\, g\, d\left(\frac{\rho w}{\rho b}\right)} \text{ ,m/s} \qquad (1)$$

$$P = \rho w\, g\, h \text{, N/m}^2 \qquad \textbf{(Serway and Jewett, 2004)} \qquad (2)$$

$$R_E = \frac{\rho b V D}{\mu_{gas}} \text{, dimensionless} \quad \textbf{(Veenman, 2004)} \qquad (3)$$

Where:

V: velocity of the biogas, m/s
P: pressure, N/m^2
R_E: Reynolds number, dimensionless
g: gravitational acceleration (9.1 m/sec^2)
d: inclined displacement of the manometer water, m
h: pressured head, m
ρw: density of water in manometer 1000 kg/m^3
ρb: density of biogas taken as 1.15-1.2 kg/ m^3 **(Werner *et al.*, 1989)**
D: port diameter of biogas burner, m
μ_{gas}: biogas viscosity (1.24×10^{-5} kg/m-s) **(Zicari, 2003)**

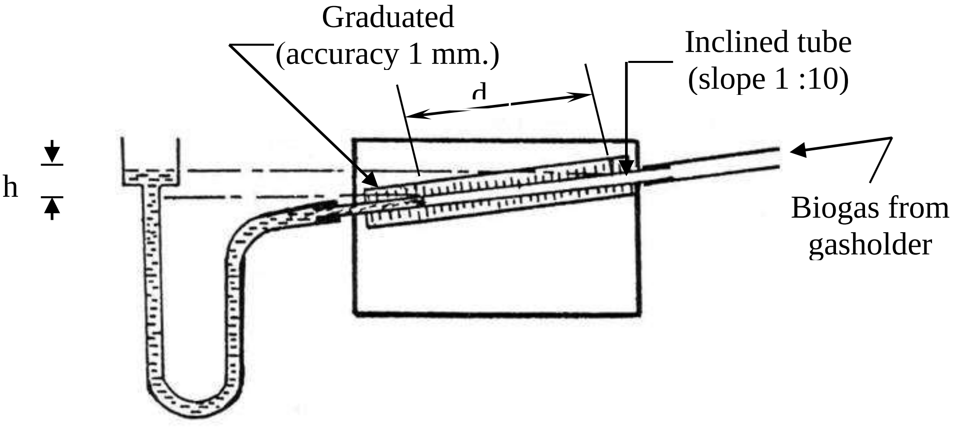


Fig. (3): Schematic diagram of the inclined manometer

2.5. Biogas flow rate

The gas meter model ACTARIS G2.5 GALLUS 2000 was used to measure the biogas flow rate in liter/min releasing from the gasholder. The biogas flow rate was 0.9 liter/min. The biogas flow inside the port of burner is considered laminar, due to a low inlet Reynolds number 610 **(Trigas, 2002)**.

2.6. The voltage and temperature measurement

The voltage values (mV) were measured by K-type (NiCr-Ni) thermocouples of 0.5 mm diameter (accuracy: ±0.5 °C) connected to digital multimeter model HILIX DT-830B, meanwhile the temperature at the same point and time was measured by J-type 0.6 mm (Iron / copper-nickel (Constantan)) thermocouple connected to a digital temperature controller model XMTD.

An experimental setup was constructed in the biogas laboratory of Agricultural Engineering Department, Faculty of Agriculture, Suez-Canal University to determine the temperature and voltage of the biogas burning as shown schematically in Fig. (2). It consists of a gasholder attached with gas meter, control valve and burner. A thermocouple type J and type K, digital temperature and digital multimeter indicator were connected to the setup to measure the flame temperature and voltage. These measurements were executed on the biogas collected every day at the second replicate retention time (25 days) in gasholder by the water displacement method. The percentage of methane in each of the above samples was determined using a gas chromatography GC (Chrompack CP 9001). A sample of 5 liters of biogas was taken from gasholder through gas meter to the burner. The biogas was released and allowed to move through the port 3 mm diameter **(Leung and Wierzba, 2008)** by opening the control valve and igniting in the air (Fig. 4). The steady state flame temperature and voltage were measured in reaction zone by a temperature and voltage measurement system. The reading of the digital temperature and voltage indicator gives the direct value of flame temperature (°C) and voltage (mV) of the biogas burned. As shown in Fig. (4), the length and thickness of biogas flame were measured using digital camera TARGA model VQ2110 and AutoCAD 2004 computer program.

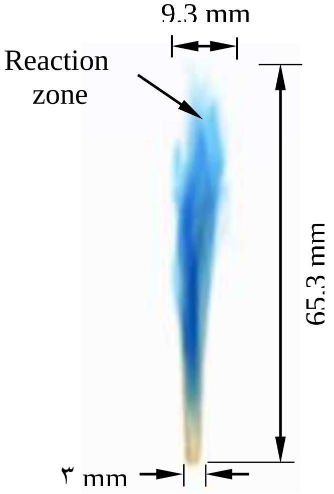


Fig. (4): The Camera image of biogas flame igniting in the air.

RESULTS AND DISCUSSION

The relationship between carbon dioxide, methane of the collected biogas and pH value of the mixture solution inside the bench-scale digester is shown in Fig. (5). The pH value gradually increased in the second replicate hydraulic retention time from 7.08 to 8.12. This refers to the digested material (cattle dung) has a high buffer capacity. Meanwhile, in the same time the carbon dioxide was gradually decreased and methane production gradually increased to reach to the balance state inside the digester.

Fig. (6) shows the variation of flame temperature of the biogas collected at different days of the second replicate of hydraulic retention time. It can be seen that, the flame temperature of the biogas sample increased with the increasing of the methane percentage. Fig. (7) reveals the voltage due to flame temperature of the same sample. The voltage increased with the increasing of the methane percentage. Meanwhile, Fig. (8) shows the relationship between temperature and voltage of the flame. The voltage increased with the increasing of flame temperature. This result is in agreement with the data published by **Wheeler and Ganji (2004)**.

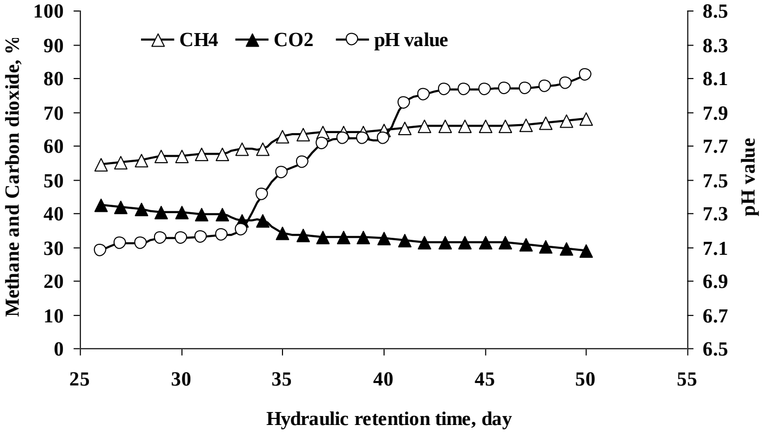


Fig. (5): Relationship among the methane, carbon dioxide percentage and the pH value during the second replicate of hydraulic retention time.

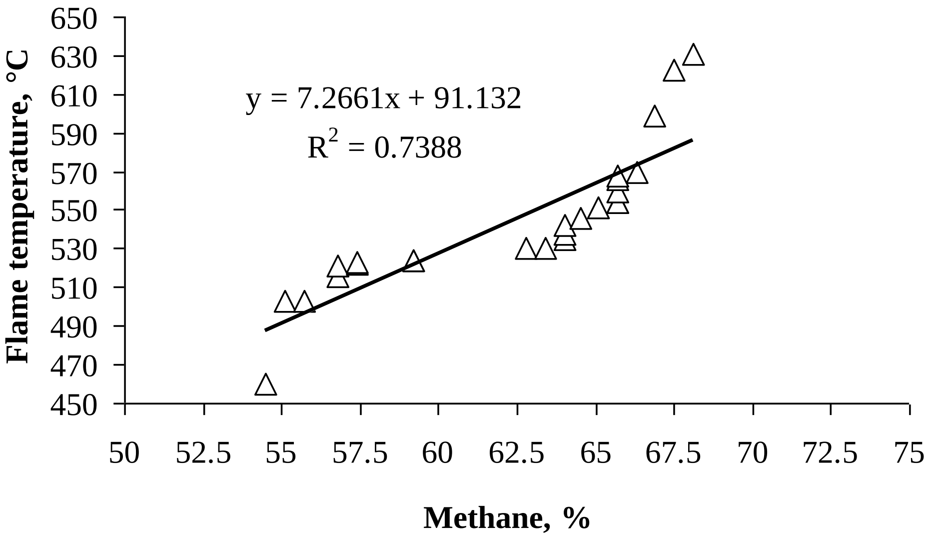


Fig. (6): Relationship between the flame temperature and the methane content of biogas.

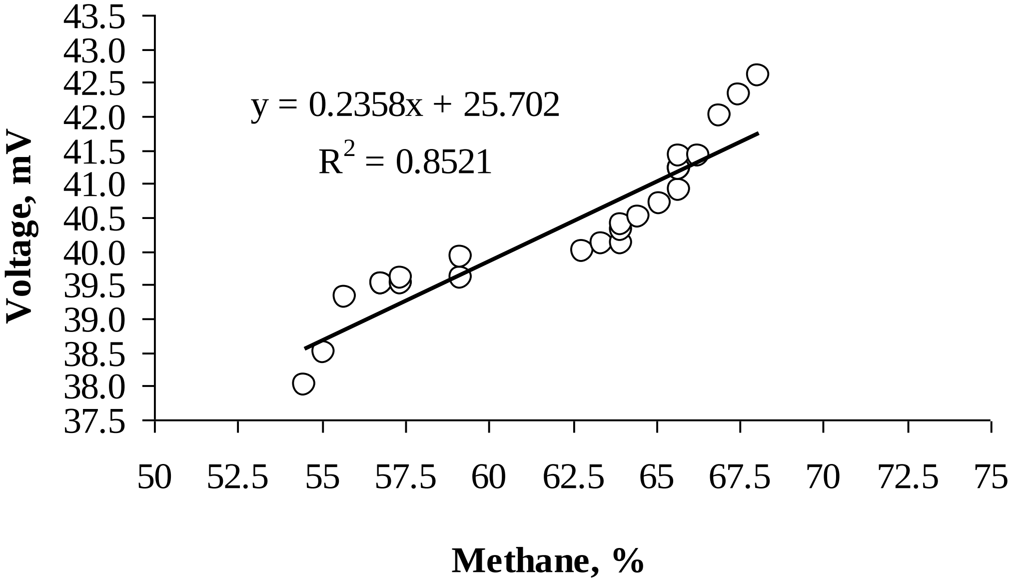


Fig. (7): Relationship between the voltage due to flame temperature of biogas and the methane content.

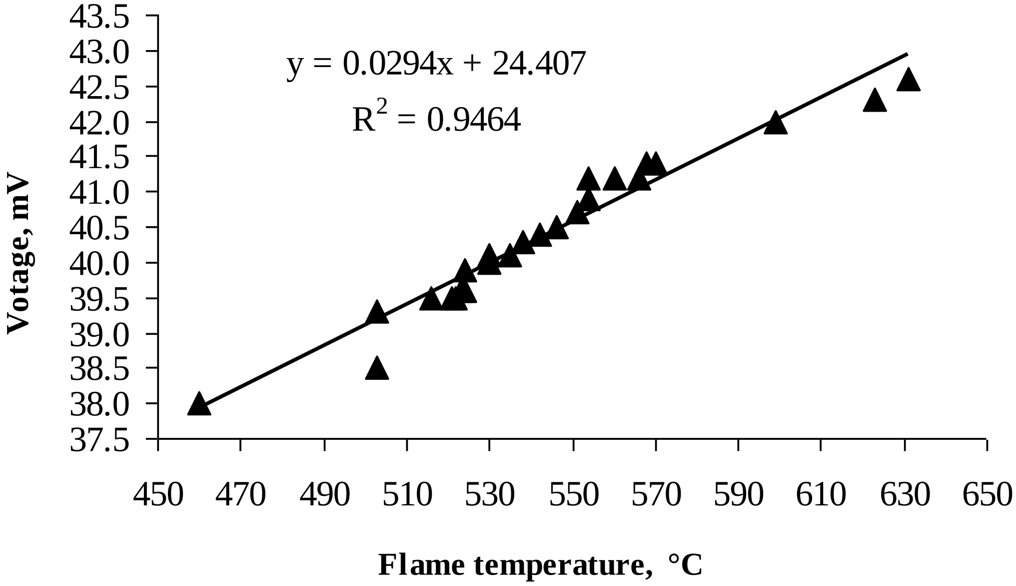


Fig. (8): The relationship between voltage and the flame temperature of biogas.

Due to the obvious reason the temperature and its voltage are considered as an indicator for the methane percentage in biogas when is burning. The obtained results in the previous section can be used to determine the methane percentage of biogas as a function of its flame temperature and voltage.

CONCLUSIONS

From this study the following conclusion can be drawn as:

- The average velocity of biogas passing through the port of burner was 2.1 m/s and the average biogas pressure in gasholder was 996 mbar.
- The biogas flow rate through the port of burner was 0.9 liter/min and had a laminar flow, due to small Reynolds number 610.
- The pH value and methane percentage were gradually increased from 7.06 to 8.12 and from 54.5 to 68.1 %, respectively. Meanwhile, the carbon dioxide gradually decreased from 42.5 to 28.9 % at the same time.
- The minimum flame temperature and voltage were 460 °C and 38 mV, respectively at methane content of 54.5 %. Meanwhile, the maximum flame temperature and voltage were 631 °C and 42.6 mV respectively at 68.1 % methane.
- The results indicated that, the relationship between the flame temperature and voltage was found to be directly proportional to methane percentage.
- The determination of biogas quality (methane percentage) was possible to achieve by using the physical properties of biogas burning such as flame temperature and voltage.

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الملخص العربي

تقدير محتوي الميثان بقياس درجة حرارة وفرق الجهد للهب الغاز الحيوي المشتعل

د. محمد علي عبد الهادي*

يهدف هذا البحث إلي قياس نسبة الميثان في الغاز الحيوي معتمداً علي الخواص الفيزيائية لاشتعال الغاز الحيوي من درجة حرارة لهب الاشتعال وفرق الجهد بواسطة ثرموكابل لقياس درجة الحرارة وفرق الجهد.

أجريت تجربة معملية في الوحدة المعملية للغاز الحيوي بقسم الهندسة الزراعية – كلية الزراعة - جامعة قناة السويس علي خليط من روث الماشية ومخلفات الدواجن بنسبة خلط ٥٠:٥٠ ٪ مادة جافة كلية (٧,٨ ٪ مادة جافة كلية في الخليط) بالتخمر اللاهوائى نظام تغذية مستمرة تحت درجة حرارة (٣٨ م°) في مدي الميزوفلك وبدون تقليب لوقت استبقاء ٢٥ يوم كرر مرتين لثبات إنتاج الغاز الحيوي في مخمر أفقي مصنع من الحديد المجلفن بسمك ١,٥ مم وبقطر وارتفاع ٢٥٠ و ٤٥٠ مم علي التوالي وحجم صافي لتخمر المادة ١٧ لتر.

تم قياس كمية الغاز الحيوي الناتج باللتر بالإزاحة الحجمية ورقم الأس الهيدروجيني في المادة المتخمرة يومياً وكذلك ضغط الغاز بالملي بار في خزان الغاز وسرعة خروج الغاز متر/ثانية من خلال فتحة الاشتعال قطر ٣ مم. تم إشعال حجم ٥ لتر من الغاز الناتج يومياً وتم قياس درجة حرارة اللهب (م°) بواسطة ثرموكابل J type وكذلك فرق الجهد (ملي فولت) بواسطة ثرموكابل K type تم تقدير نسبة الميثان في الغاز الحيوي الناتج لنفس العينات بطريقة الغاز كروماتوجراف gas chromatography

<u>وقد توصلت النتائج إلي:</u>

- السرعة المتوسط لخروج الغاز الحيوي من فتحة الاشتعال ٢,١ متر/ ثانية بينما كان متوسط الضغط في خزان الغاز ٩٩٦ ملي بار
- كان معدل سريان الغاز الحيوي خلال فتحة الاشتعال ٠,٩ لتر/ دقيقة وكان السريان رقائقي وذلك لانخفاض رقم رينولدز ٦١٠
- زادت قيمة رقم الأس الهيدروجيني للمادة المتخمرة خلال المكررة الثانية لوقت الاستبقاء من ٧,٠٦ الي ٨,١٢ وكذلك نسبة الميثان من ٥٤,٥ الي ٦٨,١ ٪ علي التوالي بينما في نفس الوقت انخفضت نسبة ثاني أوكسيد الكربون من ٤٢,٥ الي ٢٨,٩ ٪ علي التوالي

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*مدرس بقسم الهندسة الزراعية – كلية الزراعة – جامعة قناة السويس

- سجلت أقل درجة حرارة للهب ٤٦٠ م° وكذلك اقل فرق جهد ٣٨ ملي فولت عند نسبة ميثان ٥٤,٥ ٪ بينما كانت أعلي درجة حرارة للهب ٦٣١ م° وأعلي فرق جهد ٤٢,٦ ملي فولت عند نسبة ميثان ٦٨,١ ٪

- دلت النتائج علي وجود علاقة طردية بين درجة حرارة اللهب وكذا فرق الجهد مع نسبة الميثان في الغاز الحيوي

- يمكن تقدير نسبة الميثان في الغاز الحيوي من الخواص الطبيعية لاشتعال الغاز بواسطة درجة حرارة اللهب وكذلك فرق الجهد الناتج من حرارة اللهب.