Misr J. Ag. Eng., 25(4): 1438-1453 BIOLOGICAL ENGINEERING

BIOGAS UTILIZATION FOR POWERING WATER IRRIGATION PUMP

***Ashrf Abdel-Galil** ***Mubarak M. Mostafa**
***Mahmoud A. Elnono** *** Mostafa F. Mohamed**

ABSTRACT

A simple method and technique for handling, storing and utilizing of biogas have been done. SI engine was modified to power a water pump for irrigation by using 100% biogas as fuel (gasoline starting). A gas mixing device was designed to meter biogas into air stream of amount dictated by the engine speed and the load to obtain a proper proportion of biogas and air that burn for SI engine operation. An inner tube of tractor tire was used for storing and handling biogas from the biogas digester to the engine-pump site. It was filled up with biogas by using a modified passenger car compressor.

Biogas was analyzed to determine CO_2 percentage by using alkaline $Ca(OH)_2$. The average percentage of CH_4 and CO_2 were found to be approximately 69.6% and 30.4%, respectively. The calorific value of biogas was calculated and found to be 29360.7 kJ/ m^3. A comparison between biogas and the liquid fuel (kerosene and gasoline) was made. The results showed that at 2500 rpm engine speed, specific energy consumption under biogas mode was decreased by an average of 80.3% and 79% when compared to gasoline and kerosene mode of operation, respectively. The total pump efficiency of biogas operation was about 58%.

Keywords: bio-fuels; biogas; gasoline engine; engine performance, pump performance.

INTRODUCTION

Energy plays a vital role for rural development. The price of oil, however, has crossed above 140 $ per barrel in the international market and is expected to increase further. Therefore, a major concern for most of scientists recently is the use and the availability of renewable energy (solar energy- wind energy- biogas -etc). At the same

*Agric. Eng. Dept., Fac. Of Agric., Ain Shams Univ.

time there are many problems in waste management. Egypt only produces a lot of tons of wastes especially organic wastes (plant residues- animal residues). **Helmy et al.** (**2003**) reported that there were 31.42 M ton/ year of plant residues and 55.37 M ton /year of animal residues and at the same time we have problem with energy like any other developing country. So biogas is a useful source for solving those problems.

Producing biogas from treating organic wastes can provide us with acceptable amount of energy and also a high quality fertilizer and work as odor controller (environmental friendly). Biogas is not just for agricultural wastes but also for industrial (**Lettinga and Van Haandel, 1992)**. In Egypt the first biogas digester was in Elgabel el-asfer farms in 1939 to treat sewage sludge (**Alaa El-din et al, 1983**). After that many digesters have been built in Egypt by the scientists to evaluate biogas production and the materials which can be used to feed the digester and their effects on biogas production and methane concentration in the gas.

Biogas can be upgraded for utilizing in internal combustion engines to increase its calorific value by removing H_2S and/or CO_2, also it can be compressed. The methods selected for the treatment of biogas will depend upon the intended use of the gas and the composition of the gas.

Compressing biogas reduces storage requirements; sometimes the production pressure of a biogas source does not match the pressure requirements of the gas utilization equipment. Compression can eliminate the mismatch and guarantee the efficient operation of the equipment. Moreover, large biogas systems rely on compression to reduce the size of the gas storage facility or to transport the biogas to a pipeline (**Walsh et al., 1988**).

Internal combustion engines have been fueled by biogas from municipal digester systems for many years ago with varying degrees of success. In recent years, this application has been extended to agricultural and industrial systems for a variety of power requirements. Biogas can be used in both CI (compression ignition) engines and SI (spark ignition) engines **(Kofoed and Hansen, 1981)**. The self-ignition temperature of biogas is high and hence it resists auto ignition, this is desirable feature in spark ignition engines, as it will reduce the chances of knock **(E.Propatham et al., 2007)**

In general, using biogas as a fuel has the following advantages **(Robert et al., 1998- House, 1981)**:

1. The combustible constituent (methane) makes it a good fuel for internal combustion engines, 2- It's a by-product of waste treatment and thus it's free excepting low capital investment required for the handling system. 3-The gas needs only, in most cases, trapping and condensation. 4- It has a very high octane rating. 5- It leaves little or no more carbon deposition in the cylinder or on the piston. 6- It greatly reduces the amount of sludge buildup in the oil, and thus means longer distances between oil changes. 7- It does not dilute the oil on the cylinder walls during engine start up like liquid fuels do, and (with numbers 5 and 6) promotes longer engine life. 8- It has no tetraethyl lead to foul spark plugs and pollute the air. 9- It mixes better with air than (liquid) gasoline, resulting in a better ignition in the cylinder.10- It results in less valve burning. 11- It burns clean and without as many harmful pollutants as other fuels.

Therefore, the aim of this research is to:

1- Investigate the possibility of handling, storing and utilizing biogas; 2- Design a gas mixing device to meter biogas into air stream; 3- Modify and convert SI engine to power a water pump for irrigation by using 100% biogas as a fuel; 4- Compare the output power of using biogas with the liquid fuel (kerosene and gasoline).

MATERIALS AND METHODS

A ready- made biogas was transported from a biogas digester of Ag. Research Center- Moshtohor to Ag. Eng. Dept., Ain Shams Univ., where the experiments were carried out. It was transported in the inner tube of tractor tire that was filled up by using a modified passenger car compressor. Biogas was analyzed to determine the average percentage of CH_4 and CO_2. SI engine was modified and converted for biogas operation by designing a mixing device to suit the inlet pipe in order to give the proper biogas/air mixture. The engine was run on 100% biogas-fuel; except that little gasoline is consumed for starting up, to power a water irrigation pump (direct-coupled).

The following materials and methods were used:

1- Equipment and instrument:

1-1 Engine: A single cylinder four stroke air cooled spark-ignition (SI) engine (Robin Ey-15Dk) was used.

It has the following specifications:

No. of cylinders	:	1 cylinder
Displacement	:	143 cc (8.73 cu. In.)
Maximum output	:	3.3 HP/ 4000 rpm (2.475 kW)
Continuous output	:	2.2 HP/ 3600 rpm (1.65 kW)
	:	1.9 HP/ 3000 rpm (1.425 kW)
Fuel	:	Gasoline (starting)/ Kerosene
Dimension (L x W x K)	:	303 x 323 x 368 mm

1-2 Pump: Robin PKK-201pump was used. The pump specifications were

Type	:	Centrifugal pump
Connection diameter	:	2 in (5.08 cm)
Delivery volume	:	132 usg./min (0.5 m^3/ min approx.)
Total Head	:	ft (25 m)

1-3 Speedometer: a digital tachometer (EXTEC) was used to measure the engine rpm during operation.

For measuring the other test variables the following instruments were used: pressure gauge, stopwatch, measuring cylinder and flow meter.

1-4 Compressor: Fig (1) shows a steel joint that was used to modify the compressor in order to be connected with the digester outlet to deliver the biogas from the digester to the compressor where biogas was compressed in to the inner tube, as shown in fig. (2) for storing and transporting from the biogas digester to the engine-pump site. The inner tube also acted as a buffer for allowing, approximately, a constant pressure downstream of the tube that connected the inner tube with mixing device.

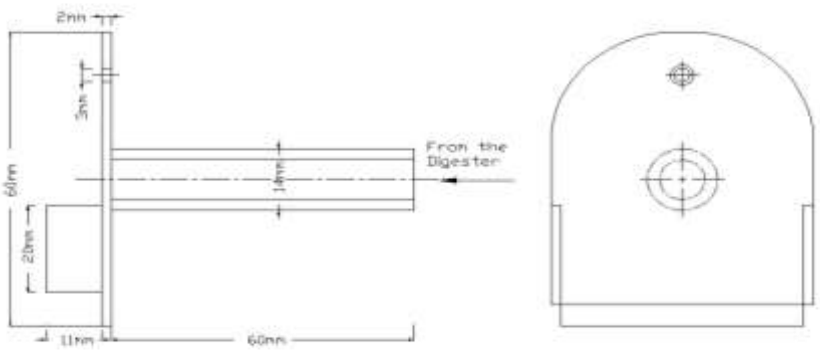

Figure (1): steel joint is used to join the compressor with the digester outlet out part together.

Figure (2): biogas filling system from gas holder to inner tube

The compressor specifications were

Type	:	Passenger car compressor(TEMP-1M)
Voltage, V	:	12
Current, A, average	:	8
Pressure, psi (kPa), maximum	:	Up to 60 (400)
Capacity, m^3/s, when inflating up to 25 psi (180 kPa)	:	0.00025
Mass, kg	:	2.0
Dimensions, mm	:	213x154x110

2- Engine modifications

SI engine conversion to biogas fueling involved engine modification as the following:

2-1 Mixing device: A gas mixing device was designed according to the recommendation of Von Mitzlaff (1988). It was a T-joint with a gas pipe that was protruding into the device as shown in fig. (3). the gas pipe was cut oblique shape, with its opening facing the engine inlet. The protruding section increased the active pressure drop for the gas to flow into the mixing device that joined the air filter and carburetion system together.

2-2 Spark gap setting: Jewell (1986), cited by Walsh et al. (1988), stated that the use of spark gap between 0.017 and 0.030 inches for biogas proved to be adequate with no noticeable difference in performance within this range. Thus, a spark plug of 0.55 mm (0.022 in) was used which operated successfully with good performance.

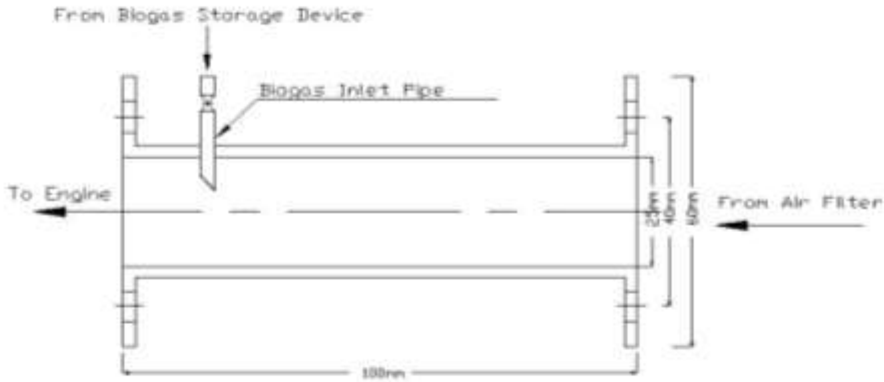

Figure (3): gas mixing device

2-3 Spark timing: Since biogas typically has a slower flame velocity relative to other gases fuels, spark timing must be retarded. Jewell et al. (1986), cited by Walsh et al. (1988), noted that the optimum spark timing for biogas of 60% methane to be between $33^o$and 45^o BTDC. In this study, however, the engine is timed by gradually regulating the point in the cycle where the spark occurs at the spark plug until ensuring smooth combustion and maximum performance of the engine operation.

2-4 Compression ratio: Although optimum compression ratios for a biogas fueled engine has been determined to be in the range of 11: 1 to 16: 1 (Walsh et al., 1988), a partial compensation can be achieved by raising the compression ratio to that range. Moreover, this will accomplish with increases the mechanical and thermal load on the engine (ISAT, 1991). Therefore, the engine used in this study (gasoline (starting)/ kerosene), was found to be explicitly suitable for running on biogas.

3- Experimental procedures and measurements:

3-1 Biogas analysis: biogas consists of two important kinds of gases most of the time which should be concerned **(House, 1981)**. There are the flammable and nonflammable gases. Coincidentally, the major constituents of almost any biogas are CH_4 and CO_2, which fall into the previous two categories. Since CH_4 and CO_2, generally, comprise 98% or 99% of any biogas, a reasonable estimation of CH_4 percentage in biogas might be determined by, simply, extracting the CO_2. Thus, in this study, biogas was passed through alkaline ($Ca(OH)_2$) 1N. CO_2 reacted with $Ca(OH)_2$ to form $CaCO_3$ (HDR, 2002)and the biogas volume before passing through alkaline (V_b) reduced to ending volume (V_e), then $\%CO_2$ could be calculated by the following equation **(House, 1981)**:

$$\%CO_2 = \left(\frac{V_b - V_e}{V_b}\right) \times 100$$

And CH_4 could be approximated by using

$$\% CH_4 = 100 - CO_2 \%$$

3-2 Biogas calorific value: The net calorific value of biogas depends on the efficiency of appliances. Methane is the valuable component under the aspect of using biogas as a fuel. Therefore, the results from the biogas analysis could be used to calculate the calorific value of biogas by using the following equations (Von Mitzlaff, 1988)

Methane density under experiment

$$\rho_{CH_{4,act}} = \rho_{CH_{4,std}} \times \frac{P_{act}}{P_{std}} \times \frac{T_{std}}{T_{act}}$$

Actual calorific value

$$\mathbf{H_a, act.} = \frac{V_{CH_4}}{V_{tot}} \cdot \rho_{CH_4,act} \cdot H_{u.n}$$

Where:

$\rho_{CH_{4,act}}$	:	methane density under experiment
$\rho_{CH_{4,std}}$	:	methane density under standard conditions
P_{act}	:	The pressure under experiment conditions
P_{std}	:	Standard pressure 1013 mbar
T_{std}	:	Standard temperature 0^o C (273 K)
T_{act}	:	Experiment temperature
V_{CH_4}/V_{tot}	:	Methane ratio in the biogas
$H_{u.n}$	:	Methane calorific value under standard conditions

$H_{a,act}$: Biogas actual calorific value

3-3 Liquid fuel consumption: Liquid fuel consumption (gasoline and kerosene) per unit time was determined as shown in fig. (4) By recording the required time for the engine to consume a certain amount of fuel and using the following equation:

$$F_c = (V/t) \times 3.6$$

Where:

V = Volume of consumed fuel (cm^3);

t = Time of operation (s) ;

F_c = Rate of liquid fuel consumption (l/h).

F_c was determined at different engine speed (from 1500 to 3500 rpm).

3-4 Biogas fuel consumption: The rate of biogas fuel consumption was determined by recording the test time for the engine to consume a certain amount of biogas, and at the same time the pressure of the inner tube was recorded at the beginning and ending of the test. The volume of the consumed biogas was measured under the same previous beginning and ending pressure **(House, 1981)** as shown in fig. (5). Then, the rate of biogas fuel consumption was calculated by using the following equation:

$$F_{Bc} = (V/t) \times 0.0036$$

Where:

V = Volume of consumed biogas fuel (cm^3);

t = Time of operation (s) ;

F_{Bc} = Rate of biogas fuel consumption (m^3/h).

4- Engine-pump performance: Fig. (6) Shows the experimental set up for evaluation the engine-pump performance. The experiments were initiated on running the engine by using liquid fuel (gasoline and kerosene) to power a water centrifugal pump.

Then, the engine was modified for running on 100% biogas (gasoline starting). For the each run the following procedures were utilized:-

1- Suction depth was fixed at a particular distance from the datum of the pump.
2- Pump operated at different rotation speed (1500- 3500 rpm).

At every rotational speed the discharge, total head and fuel consumption were measured.

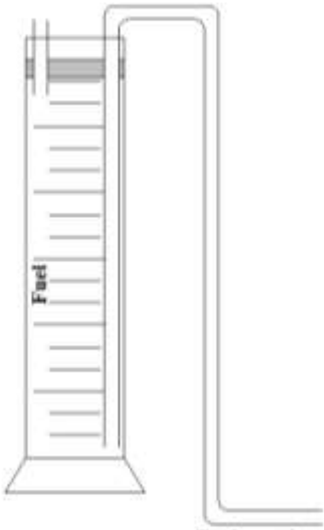

Fig. (4): Liquid fuel flow measuring apparatus.

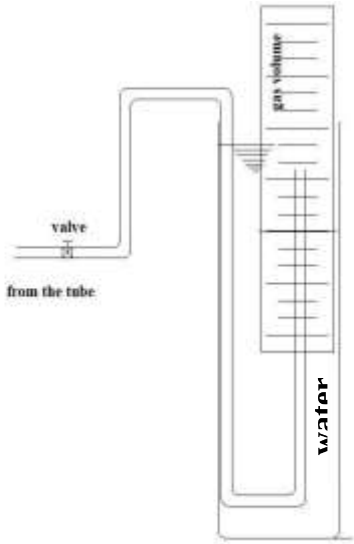

Fig. (5): Biogas measuring apparatus (David house, 1981)

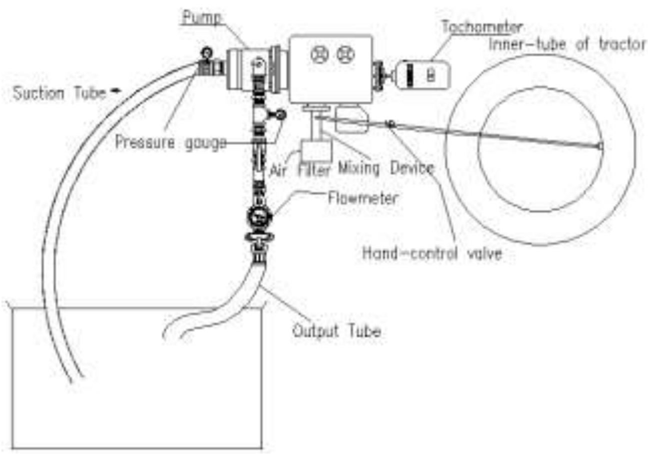

Figure (6): simplified flow diagram of biogas fueld engine for powering water irrigation pump (direct-coupled)

The water power (hydraulic power) was calculated by the following equation:

$$P = \rho . g . Q . H / 1000 \qquad (kW)$$

Where:

P = Hydraulic power or useful water power (kW)

ρ = Water density (kg/ m^3)

g = Gravitational acceleration (m/s^2);

Q = Pump discharge (m^3/s);

H = Total head of the system (m);

Engine brake power which required to drive the pump is calculated by the following formula **(ASAE, 1997) cited by (El-Gindy, 2002)**

$$Ep = f_c \times \gamma_f \times C.V \times \eta_{th} \times \eta_m$$

Where:

EP = Engine power (kW);

F_c = Fuel consumption (m^3/s);

γ_f = Fuel specific weight (assumed o.75 for gasoline, and 0.8 for kerosene, based on $\gamma_{water} = 1$)

c.v = Fuel calorific value (assumed for gasoline 11000 kcal/kg ($35*10^6$ kJ/m^3), and 10000 kcal/ kg ($35.59*10^6$ kJ/m^3)for kerosene)

η_{th} = Thermal efficiency (assumed 0.3 for gasoline, and 0.25 for kerosene)

η_m = Mechanical efficiency (assumed 0.8)

A similar equation for biogas was reported by **(Von Mitzlaff, 1988)**. It has the following formula:

$$Ep = f_c \times H_u \times \eta$$

Where:

H_u = Calorific value for biogas (calculated, kJ/m^3)

η = Assumed to be 21.2% according to (House, 1981)

The total pump efficiency is simply calculated from the date according to the relation **(White, 1979)**:

$$\eta_{total} = \frac{hydrulic\ power}{brake\ power} = \frac{\rho \cdot g \cdot Q \cdot H}{EP}$$

RESULT AND DISCUSSION

1- Gas analysis:

V_b = Beginning gas volume = (500 cm^3)

V_e = Ending gas volume = (348 cm^3)

The approximated percentages of CO_2 and CH_4 were

$$CO_2 = \left(\frac{500 - 348}{500}\right) \times 100 = 30.4\%$$

$$CH4 = (100 - 30.4)\% = 69.6\%$$

2- Calorific value of biogas:
The calorific value of biogas was determined as the following

$CH_4 = 69.6\ \%$, $CO_2 = 30.4\ \%$

$T = 305\ K^o$, $P_a = 1.013$ bar

$P_b = 0.02$ bar (gauge) = 1.033 bar (abs)

Methane density at std = 0.72 kg/ m^3

Methane density under above conditions:

$$\rho_{CH_4,act.} = 0.72 \times \frac{1.033}{1.013} \times \frac{273}{305} = 0.846\ \frac{kg}{m^3}$$

Actual calorific value

$$H_{a,act.} = 0.694 \times 0.846 \times 50000$$
$$= 29360.738\ kJ/m^3$$

3- Engine-pump performance:

3-1 specific energy consumption: Figure (7) illustrates the variation of specific energy consumption with engine speed. It's obvious that biogas operation showed lower specific fuel consumption (sfc) especially at low speed operation. At 2500 rpm engine speed, sfc under biogas mode was decreased by 80.3% and 79% on average when compared to gasoline and kerosene mode of operation, respectively. This may be due to the fact that biogas fuel evaporates more readily than liquid fuel.

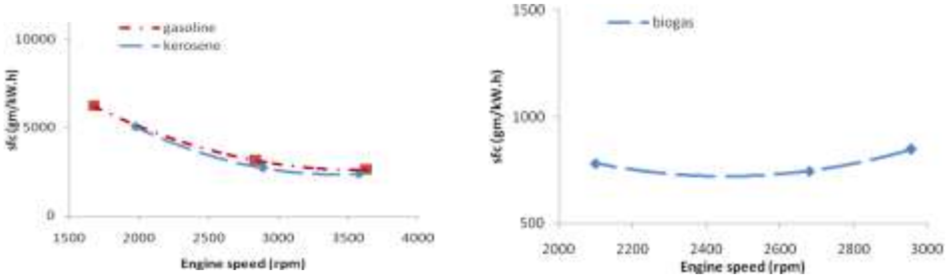

Fig. (7) Variation of specific fuel consumption with engine speed.

The variation of specific energy consumption for limited brake power range, are shown in fig (8). It is, also, clear that at low load operation, the specific energy consumption under biogas mode was lower than gasoline and kerosene mode of operation to produce the same amount of energy.

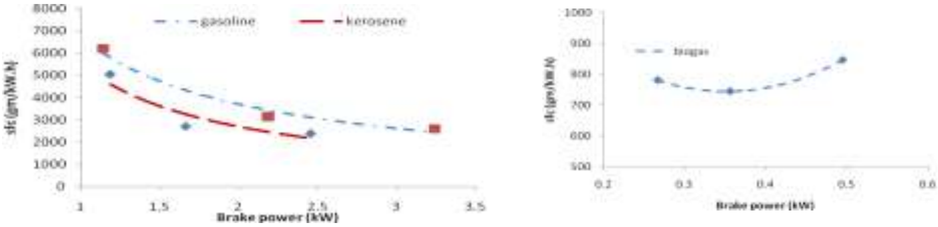

Fig. (8) Variation of specific fuel consumption with brake power.

Data for brake power as a function of engine speed are shown in figure (9) which indicated that at low engine speed the use of biogas looks more favorable, for powering the water pump that was used in this study, compared to gasoline and kerosene. At 2500 rpm engine speed the brake power under biogas mode was decreased by an average of 80% and 76% when compared to gasoline and kerosene mode of operation, respectively.

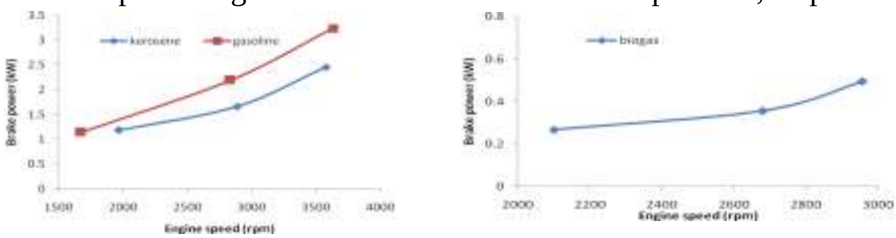

Fig. (9) Brake power as a function of engine speed.

3-2 Engine brake power and useful water pump power:

A comparison between engine brake power and useful water pump power at different engine speed, based on the experimental data, are presented in figure (10). The obtained results showed that biogas operation exhibited the lowest difference between the engine brake power and useful water pump power especially at low engine speed when compared to gasoline and kerosene operation. Consequently, a higher efficiency was expected under biogas operation than gasoline and kerosene operation. At 2500 rpm the total pump efficiency of biogas operation was approximately 58%.

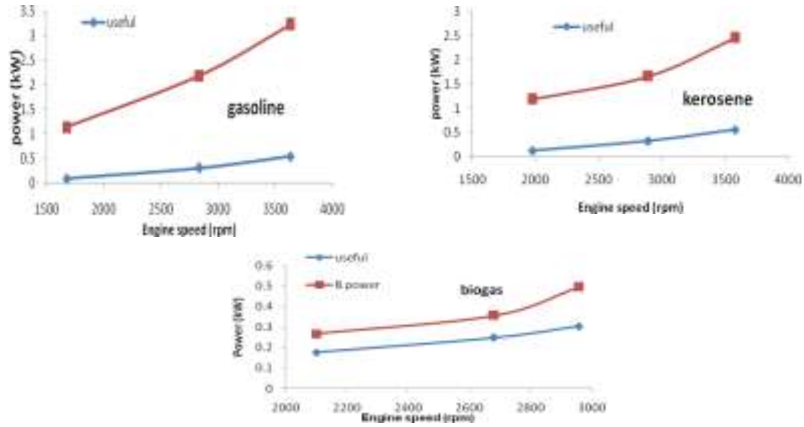

Fig. (10) Comparison between engine brake power and useful water pump power.

SUMMARY AND CONCLUSION

Energy demand in the Egyptian countryside is high and growing as a direct result from economic development and population growth. A large proportion of using energy is from oil, however, nowadays the price of oil has crossed above 140$ per barrel in the international market. So it is important to identify alternative for partial or total substation of the energy consumption. Alternative energy sources must be economically feasible and environmental friendly. Among many different types of alternative energy, Biogas from the bacterial biodegradation process of animal manure waste and plant residues under anaerobic condition proves to be one of the most promising choice for energy as well as rural development.

In this study an experimental investigation has been carried out to evaluate a simple method and technique for handling, storing and utilizing of biogas. The effect of using 100% biogas fuel to operate a small SI engine (gasoline starting) for powering water irrigation pump has been done. The engine has been modified to operate under biogas mode. A gas mixing device was designed to meter biogas into air stream of amount dictated by engine speed and the load in order to minimize biogas consumption and maximize biogas utilization.

An inner tube of tractor tire was used for storing and handling biogas from the biogas digester to the engine-pump site. It was filled with biogas by using modified passenger car compressor. Biogas was analyzed to determine the average percentage of CH4 and CO2. The obtained results showed that

1. The approximated percentages of CO_2 and CH_4 were 30.4% and 69.6%, respectively.
2. The calorific value of biogas was found to be 29360.7 kJ/m3.
3. Specific energy consumption under biogas mode was decreased by an average 80.3% and 79% when compared to gasoline and kerosene mode. At 2500 rpm engine speed.
4. Data for engine brake power as a function of engine speed showed that the use of biogas looks more favorable, for powering the water pump that was used in this study, compared to gasoline and kerosene especially at low engine speed.
5. Total pump efficiency was higher under biogas operation (58% at 2500 rpm engine speed) than gasoline and kerosene mode of operation.

In conclusion, biogas offers a promising cheap alternative fuel compared with gasoline and kerosene to operate SI engine for powering water irrigation pump.

REFERENCES

Alaa EL-Din, M. N.; S. A. EL-Shimi; M. H. Mahmoud and A. M. Abdel Aziz (1983). Biogas for Egyptian villages (Energy – Fertilizer – Forage). Soil and Water Research Institute, Agric. Res. Centre.

ASAE standards (1997). (44th Ed.). The Amirican Society of Agricultural Engineers (ASAE). Miami. USA.

House, D. (1981). Biogas Handbook. peace press, Inc Culver City, California 90230 USA.

El-Gindy, A.; M. El-Nono; A. Hamam and M. Hisham (2002). Devlopment of axial-flow pump for surface irrigation systems Misr J. Ag. Eng. 19 (2): 478-490

HDR Engineering inc. staff (2002). Handbook of public water systems. Jhon Wiley and sons

Helmy, M.A.; A.A. Abd El-Rhman; M.T. Ebid; and M.A. Hassan (2003). Expectant production of biogas and fertilizer from different residues fermentation using biogas unit. Misr J.Ag.Eng., 20 (4): 949-964

ISAT Information and Advisory Service on Appropriate Technology (1991). Biogas Digest. a publication of Deutsches Zentrum fur Entwicklung stecknologien, GATE.

Jewell, W. J. (1986). cogeneration of Electricity and Heat from biogas, Report for Science and Education Administration., U.S. Dept. of Energy, Solar Energy Research Institute, NY State College of Agriculture and Life Sciences.

Kofoed, E. and B. Hansen (1981). Gas Motors In Northeast Regional. Agricultural Engineering Service, Ithaca, NY.

Lettinaga, G. and A.Van Haandel (1992). Renewable energy, sources for fuels and electricity" Covelo, CA: Island press. Ch. 19 P: 817-839

Porpatham, E.; A. Ramesh and N. Nagalingam (2007). Effect of hydrogen addition on the performance of biogas fuelled spark ignition engine. International journal of Hydrogen energy Vol. (32) p: 2057- 2065

Robert, L. S.; T. George; E. Bayard and M. Garr (1998). Pumping station design. Butterworth Heinemann, second edition p: 423- 430.

Von Mitzlaff (1988). Engines for biogas. a publication of Deutsches Zentrum fur Entwicklung stecknologien, GATE.

Walsh, J.L. ; C.C. Ross; M. S. Smith; S. R. Harper and W.A. Wilkins (1988). Handbook on biogas utilization. the Environment, ,Health, and Safety Division Georgia Tech Research Institute Atlanta. Georgia

White, F.M. (1979). Fluid mechanics McGraw-Hill, Inc. New York. USA, p: 320-322

الملخص العربي

استخدام البيوجاز كوقود لمحرك لإدارة طلمبة مياه ري

***اشرف عبد الجليل انور** ***مبارك محمد مصطفي**

***محمود احمد النونو** ***مصطفى فهيم عبد السلام**

تزايدت فى الاونه الاخيرة معدلات استهلاك الطاقة فى الريف المصرى وهذه الزيادة نتيجة النمو الاقتصادى والسكانى. نسبة كبيرة من هذه الزيادة تتمثل فى الوقود البترولى والذى تزايد سعره مؤخرا حتى زاد عن ١٤٠ دولار للبرميل فى الاسواق العالمية مما يجعل البحث عن مصادر بديلة للطاقة امرا ملحا سواء كانت هذه المصادر قادرة على الاحلال الكلى او الجزئي للبترول مع مراعاة ان تكون هذه المصادر اقتصادية وغير ملوثة للبيئة. من بين تلك المصادر يبرز البيوجاز الناتج من التحلل البكتيرى للمخلفات الحيوانية والنباتية على حد سواء. ويعد البيوجاز مصدر مبشر من مصادر الطاقة الجديدة كما انه يساعد فى التنمية الريفية وادارة المخلفات الزراعية.

تقوم هذه الدراسة على تقييم اسلوب مبسط لتداول وتخزين واستخدام البيوجاز فقد تم دراسة تأثير استخدام البيوجاز كوقود بنسبة ١٠٠٪ لمحرك اشتعال بالشرارة (مع استخدام البنزين لبداية التشغيل فقط) لادارة طلمبة مياه للرى وقد تم تعديل المحرك ليلائم العمل تحت ظروف استخدام البيوجاز. حيث تم تصميم جهاز خلط للبيوجاز مع الهواء لمقابلة احتياجات المحرك وفقا للسرعة والحمل وذلك لتقليل الاستهلاك النوعي للبيوجاز وتعظيم الاستفادة من استخدامة. تم استخدام اطار داخلى لعجلة جرار لتخزين وتداول البيوجاز من المخمر الى موقع تشغيل المحرك والمضخة وتم ملء الاطار بالبيوجاز بواسطة ضاغط هواء لسيارة ١٢ فولت (passenger car compressor). تم تحليل البيوجاز عن طريق امرار الغاز فى محلول هيدروكسيد الكالسيوم لتحديد نسبة CO_2 ومن ثم استنتاج نسبة CH_4 كما تم ايضا حساب القيمة الحرارية للبيوجاز, ومقارنة اداء المحرك والمضخة باستخدام البيوجاز واستخدام الوقود السائل (بنزين وكيروسين) وقد اوضحت النتائج ما يلى:

١- النسبة التقريبية لثانى اكسيد الكربون والميثان هى ٣٠,٤ % و ٦٩,٦٪ على الترتيب.
٢- القيمة الحرارية للبيوجاز المستخدم ٢٩٣٦٠,٧ كيلو جول/م^3.
٣- معدل الاستهلاك النوعى للطاقة فى حالة استخدام البيوجاز كانت اقل بحوالى ٨٠,٣٪ و ٧٩٪ عنها فى حالتى البنزين والكيروسين على الترتيب.
٤- اظهرت النتائج بين القدرة الفرملية كدالة فى السرعة الدورانية للمحرك ان استخدام البيوجاز يكون مفضلا ولاسيما عند السرعات البطيئة.
٥- كانت الكفاءة الكلية للمضخة مرتفعة فى حالة البيوجاز (حيث وصلت ٥٨٪ عند سرعة ٢٥٠٠ لفة/دقيقة) مقارنة بمثيلاتها في حالتي البنزين والكيروسين.

وطبقا للنتائج السابقة يوصى البحث بان البيوجاز يعتبر من المصادر المبشرة فى مجال الطاقة وخاصة حال استخدامة كوقود لمحركات الاشتعال بالشرارة ويمكن استخدامة فى عمليات ضخ مياة الرى مما يساعد فى توفير التكاليف الناتجة عن استهلاك الوقود البترولي

---

*قسم الهندسة الزراعية- كلية الزراعة- جامعة عين شمس