BIOGAS UTILIZATION FOR POWERING ELECTRICITY GENERATION UNIT

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ABSTRACT

The aim of this research was to find out the possibility of using biogas in diesel engine and how much diesel fuel can be saved. Electricity generation unit (Engine- Generation) fueled in both conventional and dual mode. In dual mode, biogas was mixed with air and supplied with required quantity into the engine cylinder with the help of control valve and mixing device. The unit was tested to determine the engine performance characteristics, fuel consumption (fc), specific fuel consumption (sfc), thermal efficiency (η_{th}), volumetric efficiency (η_{vol}), and CO emissions. The results showed that both thermal and volumetric efficiencies in dual mode were lower than conventional mode by 28% and 11%, respectively. Fuel saving has been achieved 40% when the unit was run at (4.5) kW load.

Keywords: *biogas utilization; electricity generation; dual fuel engine*

INTRODUCTION

Shortage of conventional liquid fuel and the increase of agricultural wastes have increased interest in spreading biogas technology as a new alternative for petroleum fuel and a good way to transform organic wastes to fertilizer. The biogas is the byproduct of anaerobic digestion of organic material. It is commonly referred as "biogas" because of the biological nature of gas production **(Deshpande and Borse, 2013).**

The composition of biogas, depend on the feed material and the method of digestion, usually lies within the following ranges: 50-70% methane CH_4, 25-50% CO_2, 1-5% H_2, 0.3-3% N_2 and various minor impurities, such as hydrogen sulphide H_2S **(Jawurek et al., 1987).** Biogas calorific value depend on methane percentage, biogas (60- 70)% methane has calorific value 25 MJ/m^3, therefore it can be used for cooking, lighting, and heating **(Gichohi,1993).**

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Biogas can also be used as alternative fuel for internal combustion engine (spark ignition engine- compression ignition engine). The use of biogas in internal combustion engines dated back to Second World War when thousand of vehicle ran by sewage gas **(Razbani et. al, 2011).**

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)**. In diesel engines the temperature at the end of compression stroke is usually not more than 700^{o} C, whereas the ignition temperature of the biogas/air mixture is 814 ^{o}C. hence the injection of diesel fuel just before the end of compression stroke to ignite the gas mixture can insure the normal running of the engine and all diesel engines are normally set with an advanced injection angle. Accordingly, it is usually enough to connect the biogas pipe to air intake of the diesel engine (**ESCAP, 1981**). The governor was obviously capable of reducing the amount of diesel fuel according to the increase in biogas **(Mitzlaf and Moses, 1986).** 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 **(Propatham et al., 2007).**

In dual fuel mode, presence of up to 30% carbon dioxide improved the engine performance as compared to the same running with natural gas **(Bari, 1996).** Diesel substitution in dual mode vary from 0-80%. **Duc and Wattanavichien (2007)** mention the maximum diesel substitution was 36% at low speed, it reached a peak 48.8% at 1800 rpm before decreasing by 8% at rated speed.

The objectives of this work are:

1- Producing a biogas in an experimental digester.
2- Modifying a single cylinder, direct-injection, compression ignition engine for the use of a biogas under dual-fuel condition to generate electricity.
3- Testing the unit to determine the thermal efficiency, volumetric efficiency and fuel saving.

MATERIALS AND METHODS

Experiments were carried out at Al-Zahwiyyin village, Al-Qaliobia Governorate, Egypt. A single cylinder diesel engine (made in India) with the specifications shown in table (1) is used. It is coupled with a generator (made in China) with specifications in table (2). The experiment set-up shown in fig.(1). Fig. (2) Photographic view for the engine-generator set while

Table (1): Engine specifications

Model/type	P.J. International/BRG
Rotational speed	1500 rpm
Indicated power	10 hp
Mechanical efficiency	80%

Table (2): Generator specifications

Model	PATER INDIA MARSHAL STC-8
Output AC power	10 kVA
Output voltage	400 V
Output current	14.4 A
Frequency	50 Hz
Rotational speed	1500 rpm

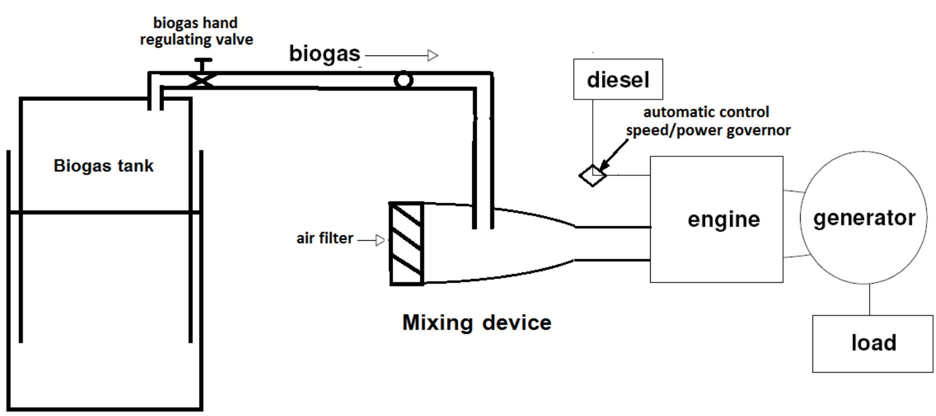

Fig. (1) A schematic view of the experimental set-up

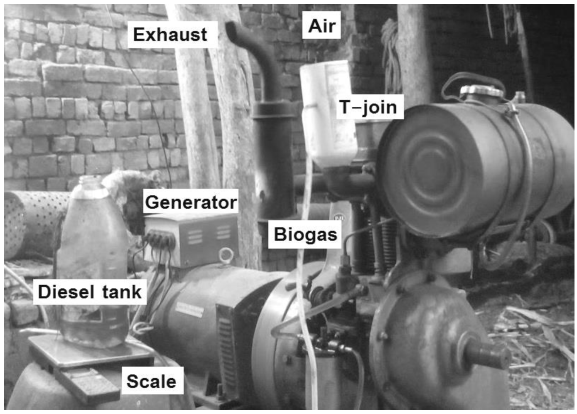

Fig. (2): Photograph of an Engine-Generator set

1- Measuring instruments:-

The following instruments were used

a- Thermo anemometer (Extech model 731A, made in Taiwan) to measure the air speed.

b- Kitchen scale (CAMRY model EN: 103, made in China) and stop watch to measure the diesel fuel mass flow rate.

c- the volumetric empirical technique to measure the biogas flow rate.

d- Tachometer (Extech tachometer) to measure the engine shaft speed.

e- Combustion gas analyzer (Extech CO80, made in United Kingdom) to measure the carbon monoxide emissions.

2- T-joint

The biogas admitted through a T-joint as in fig. (3), the objectives of the joint design are delivering the biogas in the required quantity and providing proper mixing of the air and biogas.

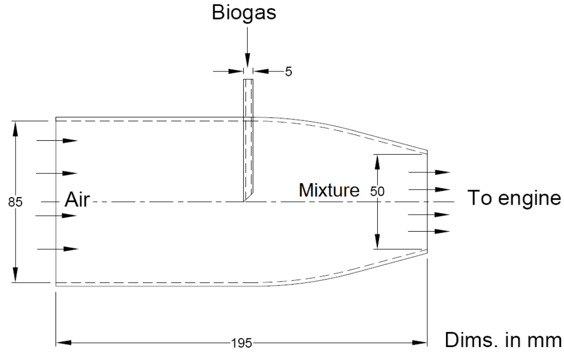

Fig. (3):- A schematic diagram of the T-joint mixing device

3- Experiment procedure

The engine was first tested on diesel mode for a load range from 0.0 to 4.5 in intervals of **1** kW to obtain basis for comparison, at each interval, diesel fuel consumption, rotational speed, air flow rate into the engine, and CO emissions in exhaust gas were measured. In dual mode the same experiment repeated but in this case biogas introduced with air into the engine through the mixing tube, the biogas flow rate was also measured. Many replicates were used for each measurement.

4- Biogas fuel

The biogas that used as fuel in dual mode was generated in experimental digester shown in fig.(4), the digester volume is (215 liter) then the biogas was collected and stored in floating drum tank.

Fig. (4):- Experimental biogas digester

5- Analysis procedure:-

- Diesel consumption (fc_D)

$$fc_D = \frac{w_1 - w_2}{t} \qquad \text{(kg/h)}$$

Where

w_1 diesel tank weight before test (kg)

w_2 diesel tank weight after test (kg)

t test time (h)

- Biogas consumption (volumetric flow rate (fc_{BG}))

$$fc_{BG} = \frac{v_1 - v_2}{t} \qquad (m^3/h)$$

v_1 biogas storage tank volume before test (m^3)
v_2 biogas storage tank volume after test (m^3)
t test time (h)

- Air flow rate $\dot{v}_{air}$

$$\dot{v}_{air} = A.C \qquad (m^3/h)$$

A engine intake area (m^2)
C air speed through intake area (m/h)

- Brake power (Bp)

$$Bp = \frac{V.I.\cos\phi}{\eta.1000} \qquad kW$$ (**Deshpande and Borse,2013**)

V generator output voltage (Volt)
I current (Ampere)
η generator efficiency (assumed 0.8)

- Specific fuel consumption (sfc)

$$sfc = \frac{fc}{Bp}$$ (**Deshpande and Borse, 2013**)

- Brake thermal efficiency (η_{Bth})

a) Diesel mode

$$\eta_{Bth} = \frac{Bp}{fc_D \cdot cv_D}$$ (**Mitzlaf and Moses, 1986**)

cv_D calorific value for diesel (34 MJ/kg)

b) Dual mode

$$\eta_{Bth} = \frac{Bp}{fc_D \cdot cv_D + fc_{Bg} \cdot cv_{Bg}}$$ (**Mitzlaf and Moses, 1986**)

Cv_{Bg} calorific value for biogas (25 MJ/kg) (**Gichohi,1993**)

- Volumetric efficiency (η_v)

$$\eta_v = \frac{\dot{V}_{air}}{V_d \cdot \frac{60\,n}{2}} \quad \text{(Heywood, 1988)}$$

V_d displacement volume
n rotational speed (rpm)

- Diesel economy (fuel saved) (**Marcelo et. al, 2011**)

$$\text{Economy \%} = \frac{fc_d\ (\text{diesel mode}) - fc_d\ (\text{dual mode})}{fc_d\ (\text{diesel mode})}$$

RESULTS AND DISCUSSION

The obtained results will be discussed under the following items.

1- Fuel consumption

In both diesel and dual mode the diesel fuel consumption increases with the increase of the load but in dual mode it reaches a point (2kW) then the increase of diesel consumption rate is lower than the diesel mode as in fig. (5), when load increase the liquid fuel consumption increase and this increase the combustion temperature and enhance the biogas combustion conditions and rate of heat released from biogas and thus diesel consumption rate decreases (**Hassan et al., 2014**).

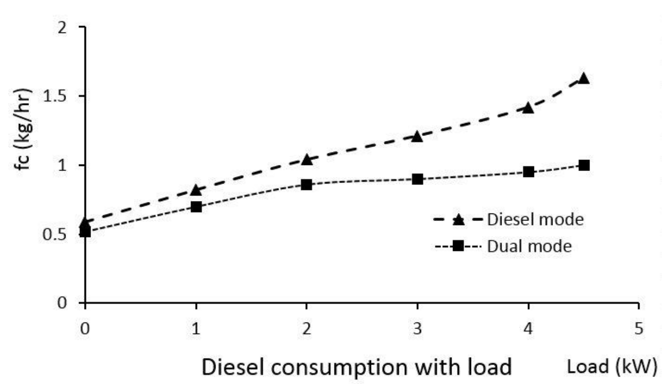

Fig. (5):- Diesel consumption with load in diesel and dual mode.

2- Specific fuel consumption

Fig. (6-a) represents the relation between specific fuel consumption (sfc) for diesel in both diesel mode and dual mode and sfc for biogas in dual mode it can be noticed the specific diesel consumption in dual mode is lower than diesel mode this is due to the biogas add to the engine increase the engine speed so the governor decreased the amount of diesel injected to the cylinder. And it's also observed from the figure it's better to run the generator-engine unit at high loads in diesel and dual mode where the sfc reaches its lowest value.

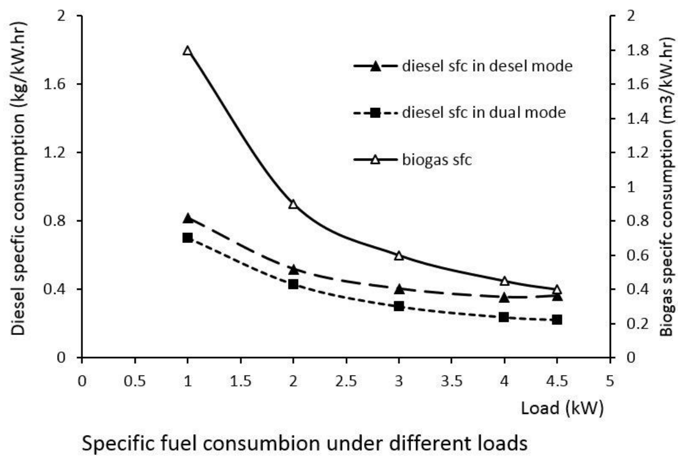

Fig. (6-a):- Diesel specific consumption in both diesel and dual mode and biogas specific consumption in dual mode

Figure **(**6-b**)** shows that the total BSFC obtained is the sum of biogas and diesel fuel, at low engine loads the total BSFC for dual fuel were higher than for diesel fuel this result indicates the lower rate of gas fuel due to the lower air-fuel ratio in the combustion chamber and the lower combustion temperature. Whereas the difference between diesel and dual fuel is much lower at higher engine loads. (3.5- 4.5) kW, where a high thermal load was imposed on the engine, the increase in combustion rate of biogas led to a significant improvement in the total BSFC with dual fuel combustion (**Bahabani et al.,2013**).

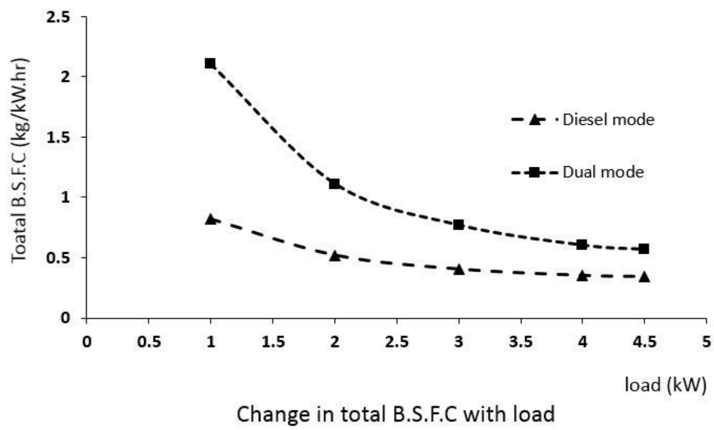

Fig. (6-b):- Total Brake specific fuel consumption in both diesel and dual mode.

3- Equivalence ratio

Figure (7) shows the effect of combustion mode on equivalence ratio with variation of in engine load at constant flow rate of biogas under dual combustion conditions. The dual mode exhibited higher fuel air equivalence ratio compared to the diesel fuel mode at all engine loads. This is mainly due to the fact that the biogas was supplied to the intake and mixed with air, hence replacing some of intake air. As biogas

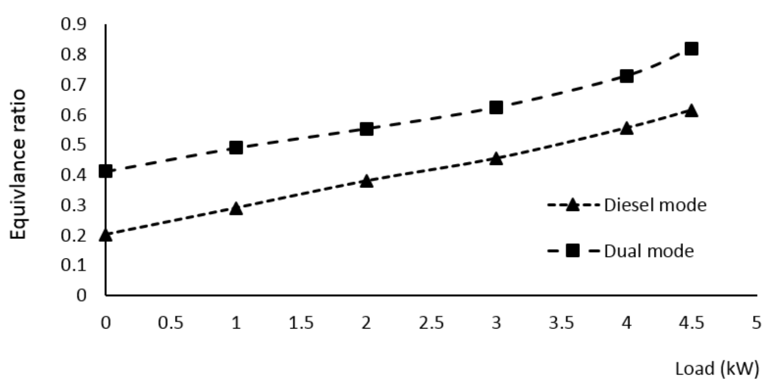

Fig. (7):- variation of fuel/air equivalence ratio related to engine load.

displaced more air, the fuel air equivalence ratio increased so as engine load increased at a constant biogas flow rate, the engine required more fuel to satisfy the imposed engine load, and hence more diesel fuel must be injected into the combustion chamber. The increased fueling then increased the fuel air equivalence ratio of the engine (**Seung and Chang, 2011**) and (**Hassan et al., 2014**)

4- Brake thermal efficiency

The brake thermal efficiency increase with the load increases as in fig. (8) it is observed that the thermal brake efficiency in dual mode operation was lower than in diesel mode operation and this is result from incomplete combustion during the combustion stroke and the 30% of CO_2 which exist in biogas consumed energy while being processed through the engine. (**Seung and Chang, 2011**) imply the decreased of thermal efficiency in dual mode to the low combustion temperature during the combustion process.

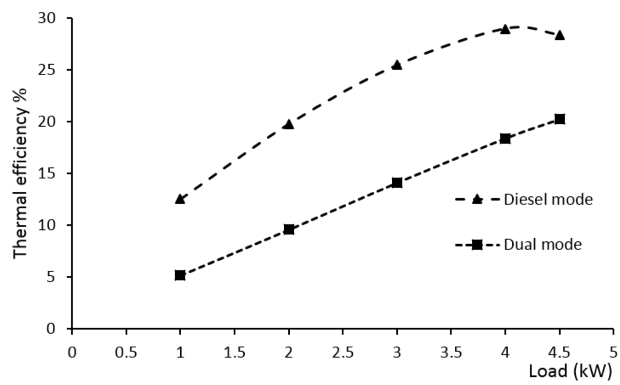

Fig. (8) Thermal efficiency in both diesel and dual mode operation.

5- Volumetric efficiency

The volumetric efficiency fig.(9) was almost constant in diesel mode operation it decreases with load but in low rate, while it decreases in dual mode operation. This can be explained the volumetric efficiency is a function of air entered the cylinder in suction stroke while in dual mode biogas substituted amount of air which reduces the quantity of air taken to the engine hence reduces the volumetric efficiency.

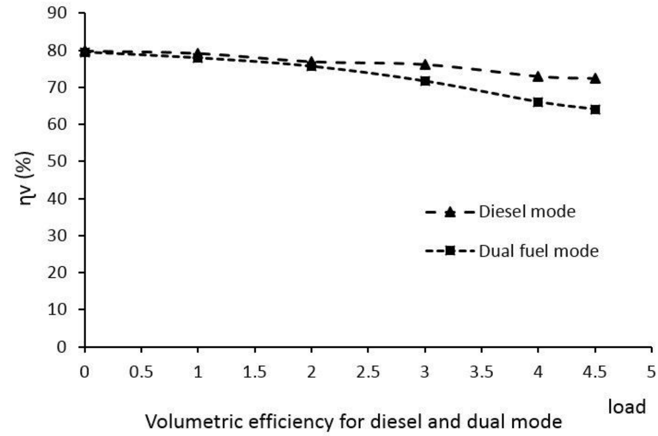

Fig. (9):- Change in volumetric efficiency with load in both diesel and dual mode

6- Carbon monoxide emissions

Carbon oxide emissions is indicated to the combustion quality so increase in CO emissions in dual mode can be explained by the amount of biogas which substituted amount of air and decrease volumetric efficiency also decreased oxygen which affect the combustion quality.

The excess oxygen in the air fuel mixture allowed more CO emissions to oxidize into CO_2 and resulted less concentration of CO, while when biogas replaced air the CO_2 content in biogas caused to increase unburned fuel in dual mode.

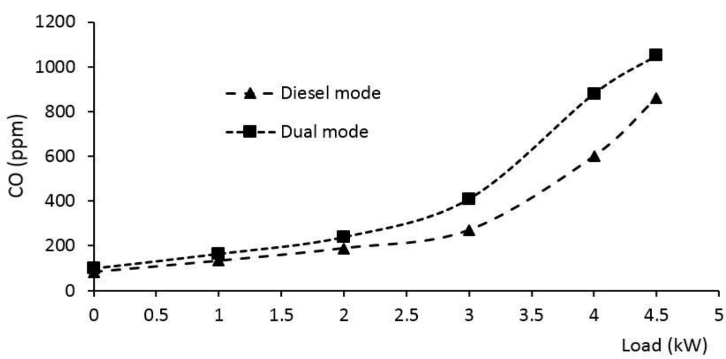

Fig.(10):- Carbon monoxide emissions in exhaust gases in both diesel and dual mode.

7- Economy (fuel saving)

As in fig. (11) it was found that at lower loads, the reduction in diesel consumption was lower, with about 12% reduction at the lowest load. The reduction of diesel increased with increase of load, it reach maximum about 40% at 4.5kW.

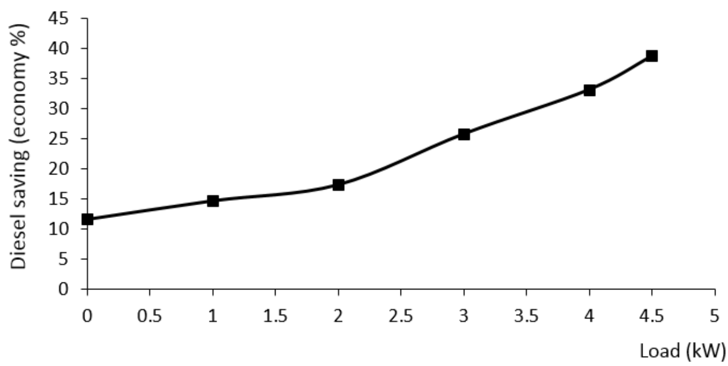

Fig.(11):- Diesel saving in dual mode.

SUMMARY AND CONCLUSION

In this research electricity generation unit consists of Diesel engine 10 hp and generator 6 kW capacity, is tested using conventional fuel (diesel) then dual fuel (biogas- diesel) to evaluate the effect of running the engine in dual mode. The result showed that:-

1- The specific diesel consumption decreased by 40% when running in dual mode.
2- 40% of diesel fuel can be saved by using biogas as a fuel in dual mode.
3- Engine efficiencies (thermal and volumetric) decreases by (28% and 11%) respectively when running on dual mode. Exhaust gas contain more CO emissions by 18% when running on dual mode.

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الملخص العربي

إستغلال الغاز الحيوي لإدارة وحدة لإنتاج الكهرباء

أشرف عبد الجليل انور* ، مبارك محمد مصطفي* ،
محمود احمد النونو* و مصطفى فهيم عبد السلام*

اجري هذا البحث لاختبار وتقييم أداء وحدة لانتاج الطاقة الكهربية تستمد قدرتها من محرك ديزل يعمل كمحرك ثنائي الوقود (ديزل- بيوجاز) ففي الآونة الأخيرة عانت مصر من انقطاع التيار الكهربى وكذلك ظهرت ازمة في الوقود.

فقد تم توصيل محرك قدرته ١٠ حصان بمولد سعة ٦ كيلووات وأجريت الاختبارات على هذه الوحدة باستخدام وقود الديزل أولا وتم قياس كل من (السرعة الدورانية- استهلاك الوقود- تصرف الهواء الداخل للمحرك) وذلك عند احمال مختلفة (صفر- ٤,٥ كيلووات), ثم أجريت نفس الاختبارات بعد توصيل المحرك باداة لخلط الهواء الداخل لاسطوانة المحرك في شوط السحب بالبيوجاز وتم اجراء نفس القياسات بالإضافة لاستهلاك غاز البيوجاز.

وكانت اهم النتائج كالتالى:-

١- انخفاض استهلاك الديزل عند إضافة البيوجاز وكان ادنى فارق في الاستهلاك (٠,٠٧ كجم/ساعة) عند عدم التحميل واقصي فارق (٠,٦٣ كجم/ساعة) عند حمل ٤,٥ كيلووات.

٢- انخفاض الاستهلاك النوعي للوقود مع زيادة الحمل في كل من الحالتين وكان ادنى قيمة للاستهلاك النوعى للوقود عند التشغيل بالديزل فقط وعند التشغيل بالنظام ثنائي الوقود (ديزل- بيوجاز) هو (٠,٣٥٥- ٠,٢٢) كجم/كيلوات.ساعة على الترتيب.

٣- انخفاض كل من الكفاءة الحجمية والكفاءة الحرارية عند إلتشغيل بالنظام ثنائي الوقود وكان اقصي انخفاض في الكفاءة الحجمية والحرارية على التوالي عند (٤,٥) كيلووات حيث وصلتا الى (٦٤%, ٢٠%) مقارنة بـ (٧٢%, ٢٨%) عند العمل بالديزل فقط.

٤- زيادة نسبة اول أكسيد الكربون عند العمل تحت النظام ثنائي الوقود فقد كانت اقصي قيمة عند التشغيل بالديزل فقط (٨٦٠) جزء في المليون وازدادت الى (١٠٥٠) جزء في المليون عند التشغيل بالنظام ثنائي الوقود وذلك عند حمل (٤,٥ كيلووات).

٥- إمكانية التوفير في وقود الديزل وذلك بإضافة البيوجاز وتشغيل المحرك بالنظام ثنائي الوقود وكانت اقصي قيمة للتوفير عند ٤,٥ كيلووات بنسبة ٤٠% من الوقود.

*** قسم الهندسة الزراعية- كلية الزراعة- جامعة عين شمس**