HEFAT2012
9th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics
16 – 18 July 2012
Malta

BIOGAS FOR PARTIAL SUBSTITUTION OF DIESEL IN POWER GENERATORS

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ABSTRACT

In recent years, agricultural farms in Peru have started to implement equipment for anaerobic digestion of the organic residues of their production. At first, the main objective of the implementation was to obtain bio-fertilizers, but in this process, biogas was also obtained. Farms in Peru did not use this biofuel in any process, which is why they freed it or burnt it in torches, polluting the environment in both ways, due to the biogas content of methane. This last fuel has a high global warming potential (GWP) and carbon dioxide, result of the biogas burning is also a pollutant. In this context, an experimental device was designed and built to evaluate the performance of a Diesel cycle engine generator set of 40 kW using diesel and biogas as fuels. The generator set had a fixed speed of 1800 RPM. The tests were initially carried out using only diesel as fuel to obtain comparable parameters. The tests were made simulating an electric load of 62.5%. After this, a conversion kit was installed to allow the use of biogas in the engine. This equipment controls the Duty Cycle, which is a value between 0 and 1 that indicates the percentage of time the injectors are opened. The kit used as input signals the generated power, the electronic governor signal and the exhaust gases temperature. Then, tests were carried out partially substituting diesel for biogas. The biogas used for the test contained approximately 40% of methane. The results indicated that for higher Duty Cycles (higher quantities of biogas), the exhaust temperatures increased, due to the superior temperature of biogas combustion. With the percentage of methane available in the biogas, the substitution rates reached 17,9% and 36,7%, maintaining the generated power and reducing significantly the consumption of diesel. This technology makes possible the modular production of electric energy in agricultural farms, usually isolated, allowing the use of biogas commonly produced in the same place with the organic residues they manage, diminishing pollution, reducing costs and using the energy for useful purposes.

INTRODUCTION

In the last years, the concern about the availability of energetic sources has increased. In this context, renewable energies have gained special importance due to the fact that its utilization contributes to the environmental care and it can be made in a decentralized way.

One of the technologies developed during the last 50 years is anaerobic digestion of residues for the production of biofertilizers and biogas, which has been very well accepted in developing countries. Initially, the main objective was to obtain the fertilizer, and the biofuel also obtained in the process was freed to the atmosphere or burnt, polluting the environment in both ways, since the biogas, constituted by methane (CH_4) mainly, is a greenhouse gas with a high Global Warming Potential (GWP) and the carbon dioxide (CO_2), result from the biogas burning process, is also a pollutant.

The need to use the energy of this biofuel for the production of useful energy brought as a consequence its utilization in internal combustion engines and generator sets for the sustainable production of electricity. Besides, when using biogas for this aim, the emission of pollutants to the environment diminishes, mainly, particulate matter (PM), due to the substitution of diesel (fossil fuel) with biogas (biofuel). This alternative constitutes an opportunity to achieve a sustainable economic development of people in rural zones away from the electricity distribution grid.

Partial substitution of diesel with gaseous fuels from different renewable energy sources is made various years ago to reduce operation costs and pollutant emissions [1]. The high temperature of biogas auto-ignition allows the use of conventional Diesel cycle engines [2,3]. The functioning of these engines in dual-fuel mode has been the topic of different research studies made by diverse authors, who seek mainly to evaluate the performance of these engines and to improve its operation in partial loads [4], objective for which, various strategies were presented, like the use of low substitution rates, the modification of the pilot fuel injection, the pre-heating of the mix air-primary fuel, the restriction of air, the modification of the load temperature with exhaust gas recirculation, the direct injection of the gas in the combustion cameras and the use of gaseous fuels with high rates of inflammability [5]. Nevertheless, the most promising results are obtained at higher loads and higher substitution rates [2].

Among the most important research studies based on Karim's strategies, the study of the performance of a compression ignition engine in dual-fuel mode can be found [4]. An engine was operated using simulated biogas (60% CH_4 – 40% CO_2) as the primary fuel and diesel and biodiesel as the pilot fuels. For all the evaluated loads, it was possible to substitute diesel totally with biogas and biodiesel as energy sources. For diesel substitutions higher than 60%, the engine starts to make noise and the temperature of the exhaust gases and the CO emissions are more affected by the substitution than by the quality of biogas [6]. Nevertheless, other studies have concluded that lower efficiencies are associated with higher substitution rates. On the other hand, the behavior of an internal combustion engine fed by a diesel-biogas mix (CH_4 = 68% and CO_2 = 30%; LHV = 22540 kJ/m^3) was studied. The thermal efficiency at 75% of the load went from 18% (only diesel) to 16%, when fed with the mix, due to the low LHV of the biogas and the lower speed of the flame front [7]. The consumption of fuel is higher in partial loads and as a result of the delay of the ignition and the poor flame propagation in the air-gas mix, negative effects are shown with high substitution rates in partial loads [2,4].

This research work pretends to establish the first steps for the use of biogas in Diesel cycle engines on big-scale in Peru with the objective of reducing the consumption of fossil fuels, contributing with the environmental care and offering the opportunity to reduce the energy costs in Peruvian enterprises.

EXPERIMENTAL MODEL

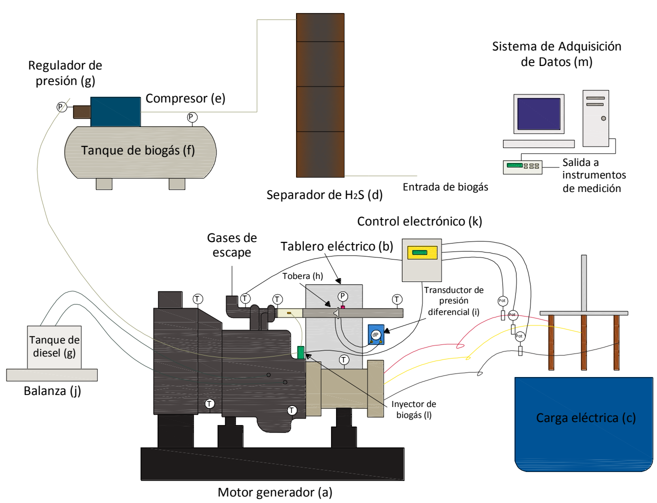

Figure 1 Experimental model

The experimental model (Figure 1) is made by the generator set, the diesel-biogas conversion kit, the electric load, the purification and compression system and the Data Acquisition System.

Generator set

A generator set conformed by a 4-cylinder Diesel cycle engine coupled to an electricity generator. The technical features of the engine and the generator are shown in Tables 1 and 2, respectively.

Table 1 Technical features of the engine

Feature	Description
Brand	Cummins
Model	4BT3.9
Functioning cycle	4-strokes
Number of cylinders	4
Type	Vertical, in-line
Unitary cylinder capacity	0.975 l
Total cylinder capacity	3.9 l
Bore	102 mm
Stroke	120 mm
Compression ratio	16.5:1
Injection system	Direct
Net power output	36 kW
Engine speed	1800 rpm
Speed regulation	Electronic
Aspiration	Turbocharged
Electric start system	24 V DC
Valves per cylinder	2 (admission y exhaust)

Table 2 Technical features of the electricity generator

Feature	Description
Brand	Stamford
Model	PI114J
Type	Synchronous alternator
Electric potential difference	220/440 V
Poles	4
Lines	4
Frequency	60 Hz
Power factor	0,8

DIESEL-BIOGAS CONVERSION KIT

The diesel-biogas conversion kit was developed at the Vehicle Engineering Laboratory of the Pontifical Catholic University of Rio de Janeiro, PUC-Rio. It allows the administration of different quantities of biogas through the variation of the Duty Cycle. This concept refers to the fraction of time that the biogas injector is opened, which has a value comprehended between 0 and 1.

The conversion kit used as input signals, the generated or consumed energy, the signal of the electronic governor and the temperature of the exhaust gases. The diesel injectors also have a regulatory function for biogas utilization. The injection of diesel was controlled by the electronic governor of the generator set, which acted over the injector. When the engine works with diesel and biogas, and the gas is injected in the air admission system, the tendency of the engine is to increase the generated power, due to the fact that the biogas adds energy to the combustion process. The electronic governor perceives this variation and makes the injectors supply a lower quantity of diesel to maintain the generated power.

For the biogas supply to the engine, a device made of polyamide was coupled to the air inlet pipe before the turbocharger. The external diameter of the polyamide pipe was 70 mm and the thickness was 12.7 mm. In both opposite sides of the pipe, two connectors were installed with an angle of 45° to allow the entrance of biogas to the air admission system. These connections were coupled with gas hoses of ¼” diameter connected to the biogas injector and this one was connected through a gas hose of ½” coupled on its other side with the compressor outlet.

Figure 2 Biogas supply device

Figure 3 Biogas injectors (dosifiers)

The amount of diesel consumed by the engine was measured using a fuel tank of 20 liters of capacity and a scale. The tank was connected through 6.25 mm diameter hoses for diesel to the feeding and return system. The scale was connected to the Data Acquisition System using a PC and a RS-232 port.

The volume of biogas consumed by the engine was measured using a turbine type flow transducer. The output signal of this instrument was on the range from 4 to 20 mA, which corresponded to flows between 0 and 7.2 m^3/h. The uncertainty of this instrument was ±1% for flows from 10 to 100% of the maximum flow.

To find the air mass flow that enters the engine, a nozzle type flow meter was used to cause a pressure drop measurable by a differential pressure transducer. A nozzle made of stainless steel was fabricated and used according to the NBR ISO 5167-1 Standard. The smaller diameter of the nozzle was 38.1 mm and the diameter ratio was 0.75 to cause the lowest pressure drop allowable and to avoid restricting the air to the engine.

The nozzle was coupled with a flange to a PVC tube with a diameter of 2”, according to the dimensions indicated in the ISO Standard mentioned before to make an appropriate measurement. A differential pressure transducer with a working range from -1 to 1 psi was used to measure this parameter.

The temperature was measured using K type thermocouples (Chromel-Alumel) in different points of the generator set: air in the inlet and outlet from the turbocharger, exhaust gases, water inlet and the outlet from the radiator, diesel, oil, biogas in the inlet and the generator set case.

PURIFICATION AND COMPRESSION SYSTEM

In this section the desulfurization, the compression and the storage of biogas is made. For biogas desulfurization, an activated carbon filter was built. It was made of an acrylic structure, similar to a tank with metal grids to contain the adsorbent. 1 kg of activated carbon was used for each 2 m3 of processed biogas.

To supply biogas to the engine appropriately, the pressure had to be constant. Due to this requirement, the biogas was compressed to 4 bar, since the pressure for biogas administration was required to be 3 bar. For this purpose, a compression system was built from a semi-hermetic compressor and a tank of 0.2 m^3 designed to support a pressure of 20 bar. The features of the compressor are shown in Table 3.

Table 3 Technical features of the compressor

Feature	Description
Displacement, 60 Hz, m^3/h	11.86
Number of cylinders	2
Suction valve, mm	18 s
Discharge valve, mm	16 s
Oil charge, kg	1.0

This compression system had an electric panel and a pressostat which activated and deactivated the compressor according to the pressure of biogas inside the tank: when the pressure is lower than the required, the compressor starts to work and when the desired pressure is attained, the compressor turns off.

To reduce the pressure of biogas to 3 bar, which is the required pressure for the biogas injection to the engine, a pressure regulator was used.

ELECTRIC LOAD

An electric resistance was used to simulate the electric load of the generator set. It was made by three copper bars correspondent to the three phases of the generator and a tank full of salty water (0.5%). To vary the energy consumption of the engine, the bars were submerged into the salty water using a manual elevator, varying the submersion depth. The generator and the electric resistance were connected through protected electric wire.

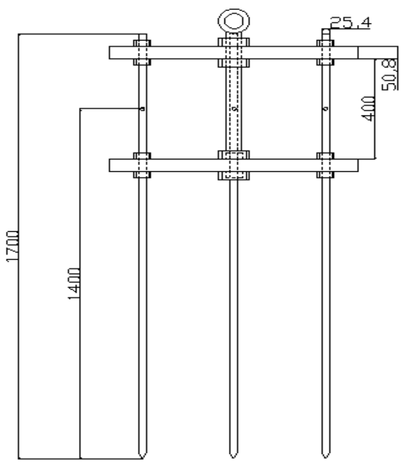

Figure 4 Details of the electric resistance

DATA ACQUISITION SYSTEM

All the signals emitted by the measurement instruments, except the scale, were acquired by the Data Acquisition System, which sent them to a personal computer (PC) through an RS-232 port, for its later processing and analysis.

The software used for the data acquisition was HP BenchLink Data Logger, which has a Windows type interface easy to configure and manage.

For the acquisition of signals from the electronic scale, LabVIEW® was used. This software had also a Windows type interface, which allowed it easy management. The data was also obtained through an RS-232 connection between the scale and a laptop.

EXPERIMENTAL PROCEDURE

Tests were carried in diesel mode and in diesel-biogas mode to evaluate the performance of the engine. The tests were made at a fixed speed of 1800 RPM, since the generator set was designed to work at this speed. For the engine mapping, tests were made for 62.5% of the maximum load.

For the tests in diesel-biogas mode, two different Duty Cycles were evaluated with a constant electric power generation of 25 kW. For this purpose, the conversion kit was used. The biogas used for the tests had been previously desulfurizes, pressurized to 4 bar and stored in the compressor tank. Two substitution rates were evaluated, correspondent to two different DCs: 30% and 50%.

The procedure for the tests in diesel-biogas mode consisted in injecting biogas in a gradual and controlled way until noting an abnormal operation in the engine. The tests were started in diesel mode, increasing the electric charge until 25 kW. The engine was kept this way until parameters like the water and the exhaust-gases temperature were stable. After this, the biogas injection through the conversion kit started, which also varied the DC from 30% to 50% during the test. The increase in the quantity of biogas supplied was made considering a few minutes to let the governor notice the addition of biogas and reduce the diesel amount supplied.

RESULTS

Figure 5 shows the variation of the temperature, of the power and the Duty Cycle during the tests.

The temperature and the DC increase for higher loads, this is caused mainly by the addition of biogas in the same electric load.

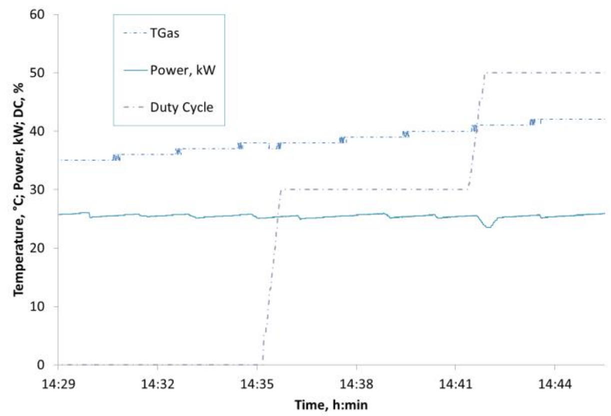

Figure 5 Variation of temperature, power and DC with time

Figure 6 shows the variation of the diesel and the biogas flow for different substitution rates.

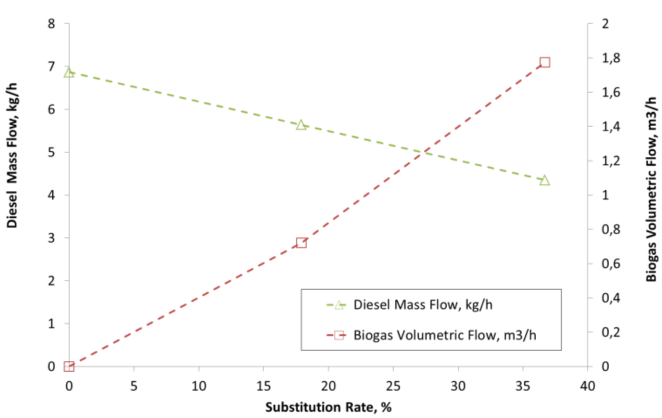

Figure 6 Variation of diesel and biogas consumption with the substitution rate

For higher substitution rates the diesel consumption is reduced and the biogas consumption is higher. The control of the biogas supply is performed by the conversion kit and the reduction of the consumption of diesel is performed by the electronic governor in the injection pump.

CONCLUSSIONS

A very important substitution rate was achieved for the maximum electric load, which is considered economically viable in this power range.

The performance of the engine in thermal aspects was not affected by the injection of biogas, which is why we can confirm it does not affect the working conditions.

In the last tests made, not shown in this study, substitution rates of 70% were achieved, which indicates that positive results can be achieved in future tests.

ACKNOWLEDGEMENTS

This paper was supported by FINCyT (Ministry of Production - Peru). The authors also wish to thank Fundo América S.A.C. and San Pablo Catholic University, Peru for motivating this research.

REFERENCES

[1] Fulford D.J., Use of dual-fuel engines with biogas in Nepal, Institute of Energy, 1984, p. 133-139.

[2] Papagiannakis R.G., Hountalas D.T, Experimental investigation concerning the effect of natural gas percentage on performance and emissions of a DI dual fuel diesel engine, *Applied Thermal Engineering*, Volume 23, Edition 3, February 2002, p. 353-365..

[3] Korakianitis T., Namasivayam A.M., Crookes R.J., Natural-gas fueled spark-ignition (SI) and compression-ignition (CI) engine performance and emissions, *Progress in Energy and Combustion Science*, Volume 37, Edition 1, February 2011, p. 89-112.

[4] Darío Bedoya I., Amell Arrieta A., Javier Cadavid F., Effects of mixing system and pilot fuel quality on diesel-biogas dual fuel engine performance, *Bioresource Technology*, Volume 100, Edition 24, December 2009, p. 6624-6629.

[5] Karim G.A., Khan M.O, A review of combustion processes in the dual fuel engine – the gas diesel engine, Progress in Energy and Combustion Sci., Volume 6, 1980, p. 277-285.

[6] Henham A., Makkar M.K., Combustion of simulated biogas in a dual-fuel diesel engine, *Energy Conversion and Management*, Volume 39, Edition 16-18, November- December 1998, p. 2001-2009.

[7] Moustafa A., El Haggar S.M., Gad El Mawla A., Matching of an anaerobic animal waste digester with a dual-fuel generator unit, *International Journal of Environment and Pollution*, Volume 12, Edition 1, 1991, p. 97-103.