Power Generation using Diesel and Biogas as Fuels for Agricultural Applications

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ABSTRACT

In recent years, the technology of anaerobic digestion has been widely adopted by Peruvian agricultural industries for the processing of their organic residues, having as the main aim the obtainment of high quality bio-fertilizers; nevertheless, biogas was also produced in the process. Since this biofuel was not used in any process, it was burnt in torches or freed directly from the digester, polluting the environment in both ways. In this context, an experimental device was designed and built to evaluate the performance of a 36 kW Diesel cycle generator using diesel and biogas as fuels for electricity generation. A diesel-biogas conversion kit was installed in the generator set to allow the variation of the Duty Cycle, a varying parameter that controls the percentage of time the biogas injectors are opened, modifying, this way, the diesel substitution rate. The performance of the unit was evaluated at different electrical charges (from 5 to 30 kW) and different diesel substitution rates (from 0 to 75%). The biogas used for the tests contained 50% of methane. During the operation with biogas, the power output kept constant due to the diesel-biogas conversion kit control. The maximum substitution rate attained was 73% at 30 kW. The specific diesel consumption was reduced to 190 g/kWh at high loads. The results indicated that for higher Duty Cycles (higher quantities of biogas), the exhaust temperatures increased, due to the superior temperature of biogas combustion. The use of biogas for substitution of diesel for power generation shows itself as an opportunity for an appropriate management of energy resources, which could benefit the operation of enterprises located far from the city with energy supply problems, allowing the use of biogas commonly produced in the same place with the organic residues they manage for useful purposes, diminishing pollution and reducing costs.

Keywords: Biogas, Diesel-Biogas, Duty Cycle, Electricity Generation.

1. INTRODUCTION

Diesel partial substitution using gaseous fuels generated from renewable energy sources has been performed many years ago to reduce pollutant emissions and operation costs (Fulford, 1984). The high auto-ignition temperature of biogas allows its utilization in conventional Diesel cycle engines (Papagiannakis y Hountalas, 2002; Korakianitis et al., 2011). The performance of these engines in dual fuel mode has been the topic of many studies developed by many authors, who have mainly evaluated ways of improving their operation at partial loads (Darío et al., 2009), objective for which many strategies were presented (Karim, 1980), such as the use of low substitution rates, the modification of the pilot fuel injection, the pre-heating of the air-fuel mixture, the restriction of the air in the mix, the modification of the temperature of the air-fuel mixture with exhaust gases recirculation, the direct injection of gas in the combustion chamber and the use of gaseous fuels with high inflammability rates. Nevertheless, the most promising results of this technology have been obtained at high loads and high substitution rates (Papagiannakis y Hountalas, 2002).

2. Experimental Model

An experimental model was designed and built to evaluate the performance of a Diesel cycle engine using diesel and biogas as fuels. For the development of the tests, the engine design was not modified: neither the diesel injection system was not altered, nor the compression rate was modified.

The experimental model was made up by three modules: the tests section (generator set and electric load), the fuel supply system (H2S filter, compressor and conversion kit) and the signal acquisition and processing system (Data Acquisition System and PC). A scheme of the experimental model is shown in Figure 1.

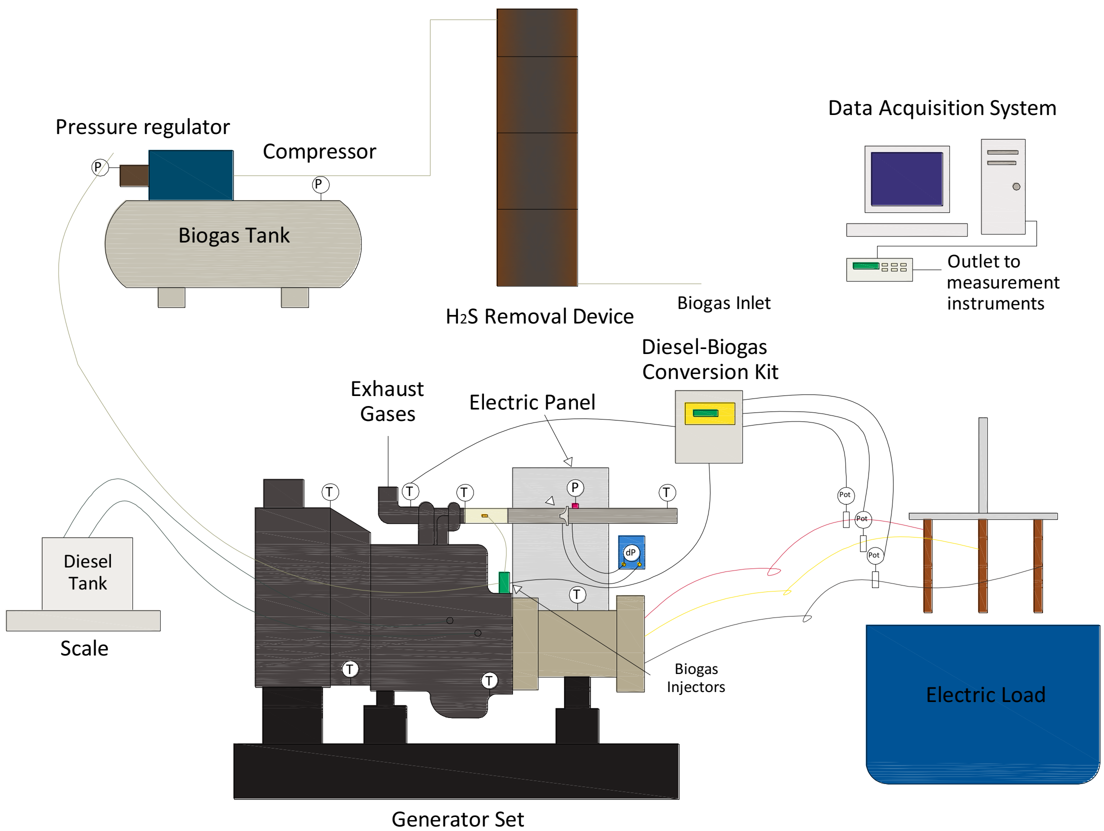

Figure 1: Experimental Model

2.1 Tests Section

The tests section is made up by the Diesel cycle generator set and the electric load.

2.1.1 Diesel Cycle Generator Set

A Cummins 4-cylinder Diesel cycle engine was coupled to a Stamford electricity generator (Figure 2). The model of the engine used was 4BT3.9.

Figure 2: Diesel Cycle Generator Set

The characteristics of the Diesel cycle engine are shown in Table 1.

Table 1: Technical Characteristics of the Engine

Feature	Description
Cycle	4-strokes
Number of cylinders	4
Type	Vertical in line
Cylinder volume	0.975 l
Total cylinder volume	3.9 l
Bore	102 mm
Stroke	120 mm
Compression rate	16.5:1
Injection system	Direct
Engine speed	1800 rpm
Speed regulation	Electronic
Aspiration	Turbocharged
Valves per cylinder	2 (admission and exhaust)

2.1.2 Electric Load

An electric resistance was used for the simulation of the electric load of the generator. The resistance was formed by three copper bars of 1”, each of them corresponding to each phase of the generator. A tank with salty water (concentration of 0.5%) was prepared for the submersion of the bars and the consequent consumption of the electricity produced. The generator set and the electric resistance were connected through protected electric cable. The electric load is shown in Figure 3.

The power produced by the generator set was controlled by the height of the bars submerged and the control panel installed in the generator set, which indicated the value of the parameter.

The generator set was instrumented with K type thermocouples to obtain the values of the temperature in different points of the equipment, mainly, the exhaust gases pipe.

Figure 3: Electric Resistance

2.2 FUELS SUPPLY SECTION

2.2.1 H_2S REMOVAL AND COMPRESSION SYSTEM

A H_2S removal and compression system (Figure 4) was developed with the objective of removing the sulfuric compounds from the biogas and uniformizing the pressure of the biogas inside a storage tank to 0.5 MPa (5 bar), since the biogas injectors require the pressure of the biogas to be 0.3 MPa (3 bar).

Figure 4: H_2S Removal (back) and Compression System (front)

The device built for the removal of H_2S was made up by two hermetic PVC cylinders with a galvanized iron structure with iron grids that contained activated carbon. This material was used to remove H_2S, since it allowed the reduction of the concentration to levels below 100 ppm.

Once the H_2S concentration in the biogas was lowered, the biofuel was compressed using a semi-hermetic Dorin compressor (H200CS model). The characteristics of the compressor are shown in Table 2.

Table 2: Technical Characteristics of the Compressor

Feature	Description
Displacement, 60 Hz, m3/h	11.86
Number of cylinders	2
Bore, mm	42
Stroke, mm	40

A control system (electric-hydraulic) was designed and built for the protection of the users and the regulation of the pressure inside the storage tank. A security pressostat activated and deactivated the compressor according to the established pressures: 0.3 MPa as the minimum pressure and 0.5 MPa as the maximum. The reduction of the biogas pressure was performed using a diaphragm type pressure reducer.

The biogas mass flow was measured using a Contech turbine type flow meter. K type thermocouples were used to measure the temperature of the biogas at the exit of the compressor with security purposes.

2.2.2 Diesel-Biogas Conversion Kit

The Diesel-Biogas conversion kit was developed and configured to regulate the biogas mass flows that enter the engine. The conversion kit operates with different Duty Cycles for the biogas injectors. The concept of Duty Cycle refers to the fraction of time that the biogas injectors are opened.

Figure 5: Air-Biogas Mixer

This conversion kit receives three different signals: a power-meter indicates the power consumption, a thermocouple installed in the exhaust pipe indicates the temperature of the exhaust gases and the electronic speed regulator provides information about the injection of diesel. With this data, the conversion kit produces an electric signal that generates a variation of the Duty Cycle that governs the biogas injectors, which increase the quantity of biogas supplied to the engine. Once the variation of biogas supply occurs, the increase in the power produced by the engine makes the electronic speed regulator reduce the quantity of diesel supplied by the injectors. The diesel consumption was measured using a scale with RS-232 connection to a personal computer.

The biogas supply was performed before the air admission collector. A tubular mixer built in polyamide was installed before the turbo-compressor (Figure 5 and 6). Two hoses were installed on both the opposite sides of the mixer with an inclination of 45° to make the inlet of the biogas easier. The two hoses were connected to the outlet of the pressure reducer.

Figure 6: Biogas Injectors

2.3 Data Acquisition and Processing System

All of the signals produced by the measurement instruments were acquired by the Data Acquisition System (DAS), which sends them to a Personal Computer for its later processing and analysis. The DAS used communicated with the PC through an RS-232 port.

3. Experimental Procedure

The experimental procedure was divided in two stages: operation with diesel and operation with diesel and biogas. For the last stage, the Diesel-Biogas conversion kit was installed. All the tests were made on a speed of 1800 RPM, since the generator set was designed to operate at that speed.

Initially, tests were made using only diesel as fuel with the objective of determining the characteristic performance curves of the engine, so that they could be used as a base for comparison with the operation with diesel and biogas.

For the operation in diesel-biogas mode, biogas was previously cleaned and pressurized. The procedure for the tests in this mode consisted in injecting the biofuel in a gradual and controlled way until noting an abnormal operation of the engine. The tests were started in diesel mode (0% biogas), then, the electric load was increased on 3 kW; the engine was kept in this state until all the parameters, such as the water and the exhaust gases temperature, had become stable. With the engine in a permanent regime, biogas was injected through the conversion kit, which varied the Duty Cycle. The increase in the quantity of biogas was performed giving enough time to the electronic speed controller to reduce the quantity of diesel injected.

The diesel injectors had a regulatory function in the diesel supply: when the engine operated with diesel and biogas and the last one is injected in the air admission system, the tendency of the engine is to increase the mechanical power produced, since the biogas gives additional energy for the combustion. The electronic speed controller perceives the variation and makes the injectors supply a smaller quantity of diesel to keep the generated power. As mentioned before, the biogas injection was performed until noting an abnormal operation: once this condition was reached, the electric load was increased on 3 kW and the same procedure was performed. The tests were developed until reaching 33 kW.

4. Results and Discussion

4.1 H2S Removal and Compression

The biogas used for the tests was produced in an agricultural farm and contained 51% of methane and 7 000 ppm of H_2S. With the activated carbon filter built, the concentration of H2S was lowered to 100 ppm, an acceptable concentration (Wellinger and Lindberg, 2000). The concentration of methane was kept the same, due to the lack of a process to remove the CO_2 present in the biofuel.

The tests made with the compressor demonstrated the appropriate performance of the control system, which activated and deactivated the compressor accurately. The temperature of the biogas at the outlet of the compressor reached 110 °C.

4.2 Diesel-Biogas Operation

The results are shown for the higher Duty Cycles and corresponding substitution rates reached.

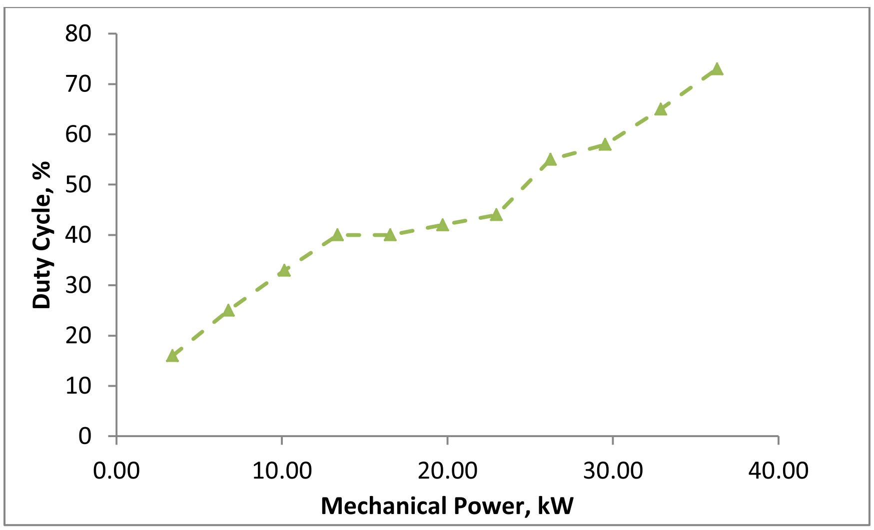

Figure 8: Duty Cycle vs. Mechanical Power

Figure 7 shows the variation of the Duty Cycle for mechanical power produced by the engine. Figure 8 demonstrates that the substitution rate corresponds to the Duty Cycle imposed by the conversion kit. The highest substitution rate attained was 73% at 36.3 kW of mechanical power (33 kWe).

Figure 9 shows that for 33 kWe, the diesel consumption reaches 9.77 kg/h, a usual value for this type of engines. On the other hand, when diesel is partially substituted by biogas, the diesel consumption lowers to 3.6 kg/h for the same electric power. The reduction in diesel consumption is clearly seen for all of the tests made.

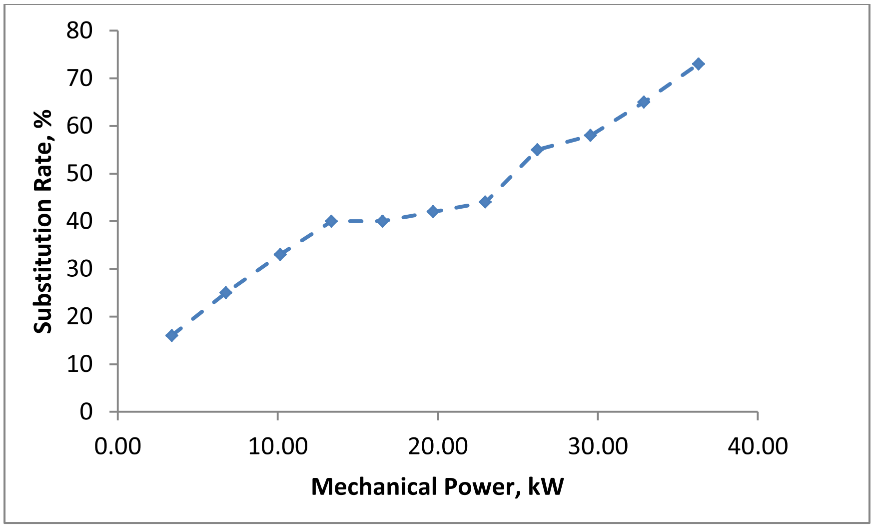

Figure 8: Substitution Rate vs. Mechanical Power

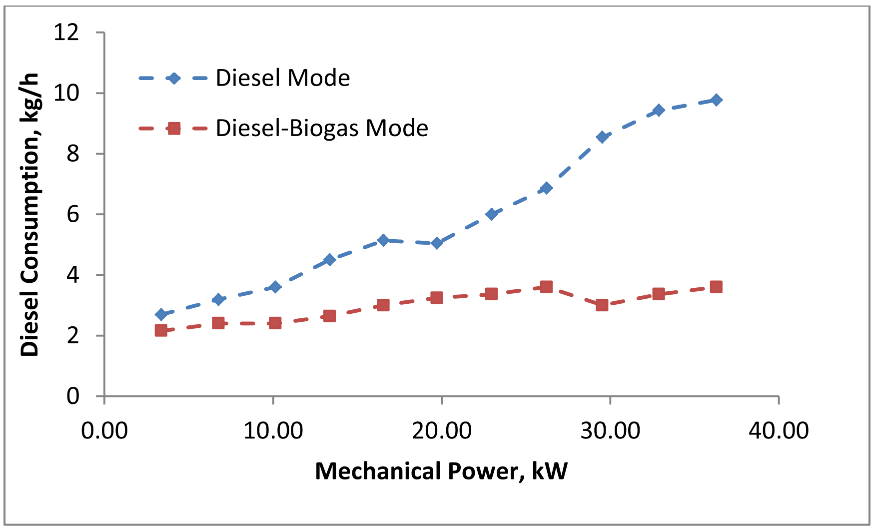

Figure 9: Diesel Consumption vs. Mechanical Power

As expected, the specific fuel consumption (diesel) reduces with the increase of the power generation, since this kind of equipment is designed to operate with the maximum efficiency at high loads (Figure 10). Also, the specific fuel consumption keeps almost constant when using biogas as fuel. This is due to the maximum substitution rate used for each test. Approximately 190 g/kWh was the lowest specific fuel consumption the engine could manage, below this diesel consumption the engine showed an abnormal operation. One of the causes of this phenomenon was the low concentration of methane in the biogas: CO_2 was also present in the biofuel lowering its calorific power.

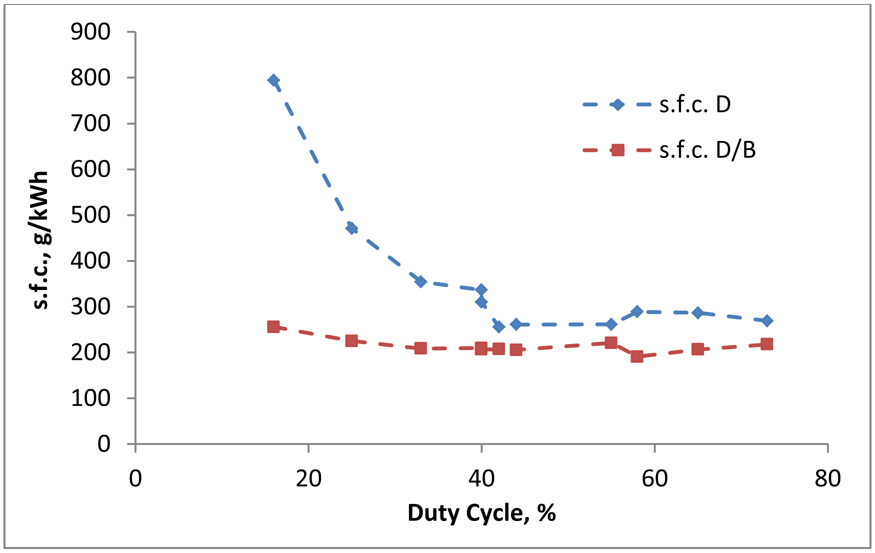

Figure 10: Specific Fuel Consumption vs. Duty Cycle

A clear increase in the temperature of the exhaust gases is shown, caused by both the increase of power generation and the addition of biogas (Figure 11).

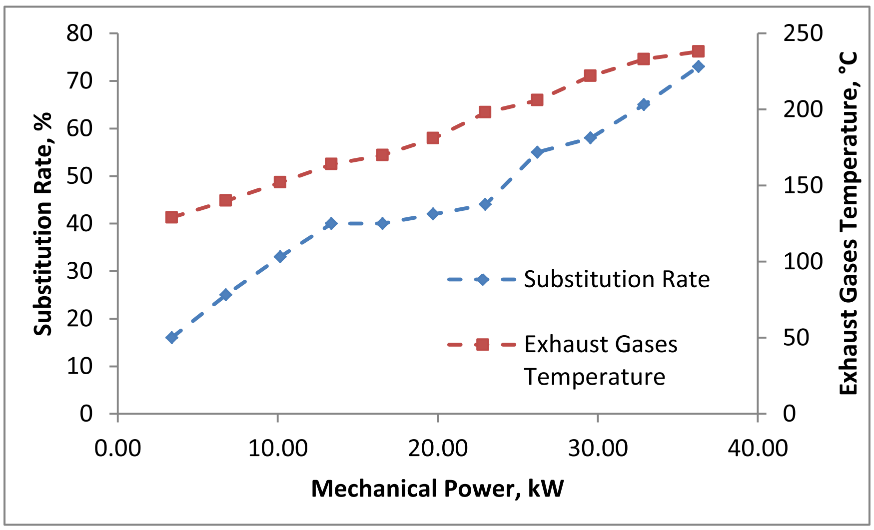

Figure 11: Substitution Rate and Exhaust Gases Temperature vs. Mechanical Power

5. Conclusions

Diesel substitution using biogas shows itself as an opportunity to use biofuels generated from anaerobic digestion, a widely used technology in Peru, for the reduction of pollutant emissions and the saving of economic resources.

The reduction of fossil fuels consumption for electricity generation allows the reduction of particulate matter and nitrogen oxides emissions. On the other hand, since the biogas is produced with very low costs in agricultural farms, this technology also allows the reduction of costs in the process of electricity generation. Substitution rates higher than 20% already imply savings when operating in peak consumption periods.

The flexibility of this technology allows the use of two fuels for electricity generation. In case of shortage of biogas, for any probable failure in the anaerobic digestion process, the equipment (generator set) is able to use only diesel, since the modifications for the use of biogas are external and do not interfere with the engine design. This way, the operation of the farms is not prejudiced with any failure in the process and normal operation can be ensured.

REFERENCES

Fulford D.J. (1984). "Use of dual-fuel engines with biogas in Nepal", Institute of Energy, pp. 133-139.

Papagiannakis R.G. and Hountalas D.T. (2002). "Experimental investigation concerning the effect of natural gas percentage on performance and emissions of a DI dual fuel diesel engine". *Applied Thermal Engineering*, Vol. 23, 3rd edition, pp. 353-365.

Korakianitis T., Namasivayam A.M. and Crookes R.J. (2011). "Natural-gas fueled spark-ignition (SI) and compression-ignition (CI) engine performance and emissions". *Progress in Energy and Combustion Science*, Vol. 37, 1st edition, pp. 89-112.

Darío I., Amell A., Javier F. (2009). "Effects of mixing system and pilot fuel quality on diesel-biogas dual fuel engine performance". *Bioresource Technology*, Vol. 100, 24th edition, pp. 6624-6629.

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