EXPERIMENTAL EVALUATION OF THE EFFICIENCY OF A DIESEL ENGINE ADAPTED TO OPERATE WITH A MIXTURE OF BIODIESEL AND NATURAL GAS

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Abstract. *Considered the necessity of reducing even more the emissions of pollutant substances to the atmosphere by internal combustion engines, it is constant the researches for new technologies that can promote a better use of the fuel utilized in internal combustion engines for electric energy generation and, at the same time, could be applicable commercially. This present work will be developed with a diesel engine, brand Cummins, 8.3 Liters, turbo charger, coupled to an electric generator, brand Onan Genset, of 150 kW, with variable power from 10 to 150kW. This system is adapted to operate in dual mode (Biodiesel – Natural Gas). Will be realized tests with a substitution rate of 85% and Biodiesel as pilot fuel, ranging from B10 to B100. In this generation system, will be studied the ideal proportion of these fuels mixtures for each specific power of the engine, which will be kept in values from 40 to 120 kW, always trying to keep the thermal efficiency as higher as possible for each mixture used. The engine will be completely instrumented to be captured all the data related to temperature, pressure, flow and analyses of the combustion gases (SO2, CO2, NO, NO2, CxHy), using a data collection system completely designed by the electric engineer department of the Federal University of Campina Grande (DEE – UFCG). All the data obtained will be stored in a dedicated computer, being available for more detailed further studies. All the parameters obtained will be compared to a pure Diesel utilization and also to the relative literature.*

Keywords*: Pollutant emissions; Dual Motor; Biodiesel;*

1. INTRODUCTION

Considered the necessity of new technologies that promote a better use of the energy sources of the earth, various entities, being governmental or private, have invested in their sectors of research and development. It is considered in application of new technologies not only the technical benefits, but also its cost benefits, because as higher as it is; the easiest will be its large-scale distribution.

In dual fuel CI engines operating with natural gas as primary fuel and a ‘‘pilot’’ amount of liquid Diesel fuel as an ignition source, the gaseous fuel is inducted along with the intake air and is compressed like in a conventional Diesel engine. The mixture of air and gaseous fuel does not autoignite due to its high autoignition temperature. A small amount of liquid Diesel fuel is injected near the end of the compression stroke to ignite the gaseous mixture. Diesel fuel autoignites and creates ignition sources for the surrounding air–gaseous fuel mixture. The pilot liquid fuel, which is injected by the conventional Diesel injection equipment, normally contributes only a small fraction of the engine power output [R.G. Papagiannakis, D.T. Hountalas, 2004].

In this research, in spite of using diesel fuel purely, it is used biodiesel in its various concentrations as a pilot fuel. Is known that biodiesel is a biodegradable fuel, derived from renewable sources as animal fats or vegetal oils, existing dozens of species in Brazil that can be used for this purpose. The biodiesel replaces totally or partially the diesel fuel in automotive Diesel engines. Regarding the terminology, the mixture of 2% of biodiesel in diesel fuel is called B2 and so on until the pure biodiesel, called B100 [http://www.biodiesel.gov.br, accessed in 02/21/2011].

The natural gas is a fuel considered purer than Diesel while utilized in combustion processes, as long as it does not generate oxides, like nitrous oxide and sulfur oxide. Its combustion, near to the complete, generates low rates of carbon monoxide for a heat capacity equivalent to other fuels, like gasoline and diesel.

In Brazil, the capacity of petroleum production and refining is near to achieve national self-sufficiency, due to the discovery of new oil wells, being the “Pré-Sal” the biggest and the most important currently. It is also decisive to achieve national self-sufficiency the construction of new refineries to supply the demand of a bigger extraction. However due to the elevated local consume of diesel fuel, it is necessary to import this product from other countries to supply all the demand. So, the use of natural gas in Diesel cycle engines that still existing expedite this process of self-sufficiency, so this application does not represent only an ecological alternative, but is also strategic for the economy of this country, considered also that Brazil has high availability of this fuel (proved reserves of 423 billion cubic meters of natural gas, according to “Agência Nacional do Petróleo” – ANP). In this way, it is possible its application in large scale and, consequently, inversion and expansion of this sector of trade balance. In other words, export diesel fuel for other countries in spite of importing it.

The objective of this study is the analysis of the behavior of a Diesel cycle engine adapted to operate in dual form under the following conditions: load variation, pilot fuel replacement rate constant and application of biodiesel as pilot fuel. In this way is made the analysis of the emissions generated and of the thermal efficiency of the motor under the new conditions and also this data is compared with the data obtained while the motor is working in traditional conditions. Comparing the results, it is searched the optimization of the mixture of fuels to obtain the highest efficiency and lower emissions rates. The engine's power is utilized for electric energy generation, so that the motor is coupled to a generator that transmits energy to the transmission lines of the university.

2. COMPOSITION OF NATURAL GAS AND DIESEL FUEL UTILIZED:

2.1. Natural Gas

It is called natural gas the compound of gases of hydrocarbons in which methane is predominant. Can be found in its associated form (in oil associated with this) or in a non-associated form. When associated, it is necessary an economic evaluation to define if its production is viable. If don't, the natural gas is re-injected in oil well to keep the pressure of extraction of oil or it is burned in safety burners to avoid an atmosphere conducive to combustion in the vicinity of the base of extraction.

The natural gas utilized in the experiment comes from typical suppliers from Campina Grande – Paraíba State – Brazil. Its average composition and respective characteristics are exposed in table 1 and table 2.

Component	**CH_4**	**C_2H_6**	**CO_2**	**N_2**	**C_3H_8**
(% in volume)	**90,09**	**6,84**	**1,56**	**1,35**	**0,16**

Tabela 1. Average composition of the natural gas utilized. (PBGÁS, 2011)

Superior Heat Power (Kcal/m³)	**9,100**
Relative air density	**0.614**
Specific Mass (Kg/m³)	**0,737**

Tabela 2. Characteristics of the natural gas utilized in the experiment. (PBGÁS, 2011)

2.2 Diesel Fuel

Diesel fuel is a product of a fraction of petroleum distillation, so it is formed basically by hydrocarbons. It can be obtained by processes of synthesis, catalytic cracking at low temperatures and by hydrogenation. It has a boiling point between 200ºC and 360ºC, and high levels of octane, which allows its use in diesel engines, which operate at high compression rates. It has average calorific value of 11000 kJ / kg. In automotive applications diesel fuel presents low emissions of carbon monoxide (CO) and hydrocarbons, but presents high emission rates of nitrous oxides, sulfur oxides and particulate materials that are extremely harmful to the environment and human health. [JOSÉ, H. J. Combustão e Combustíveis, 2004].

In this experiment the diesel fuel utilized also comes from local suppliers, like natural gas. In table 3, it is exposed the average composition of diesel fuel.

Component	**C12 H26**	**S**
(% in volume)	**98.53 %**	**1.47 %**

Table 3. Average composition of diesel fuel [Medeiros et al., 2002].

3. EXPERIMENTAL METHODOLOGY

3.1. Apparatus used

The electromechanical system of the laboratory is compound by an engine brand Cummins 6CTA of 8.3 Liters, 6 cylinders in line, turbo charged that generates until 188 kW of power at 1800 RPM. The motor is coupled to the generator brand Onan Genset, with capacity of 150kW. The engine is adapted to Dual Cycle. Besides the gas supply system the system has a heat exchanging equipment which utilizes the exergy generated by natural gas while expanding from the tanks to promote re-bleeding of the fluid cooling in the engine. To promote the connection between motor and generator, it uses a resistive load bank brand Alpha Ohmic of 150 kW.

Engine and electric generator have multiple sensors and instruments that measure fuel rate, power, engine rotation, voltage, temperature and other data other key data for monitoring the operation of the electromechanical system. Figure 1 shows the electromechanical system. Figure 2 shows the heat-exchanging equipment. Figure 3 shows the resistive load bank coupled to the electric generator.

Figure 1. Electromechanical System.

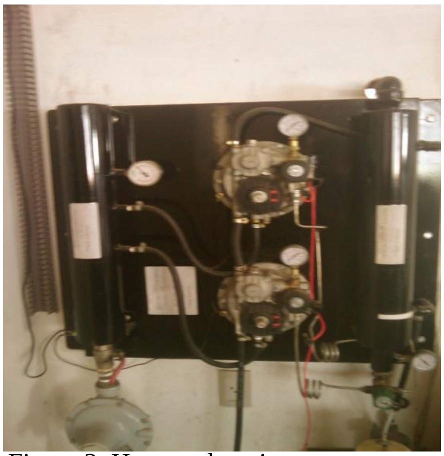

Figure 2. Heat-exchanging system.

Figure 3. Resistive load Bank

The data acquisition system is compound by the reading and processing data unity, completely developed by the Electric Engineer Department of Federal University of Campina Grande. Also, the emission data acquisition system, compound by the reading probe installed in the exhaust tube, brand Kane International Limited, model KM9106, that captures CO, CO_2, SO_2, NO, NO_2, C_xH_y and O_2 emissions. However, in this work the focus is only on thermal efficiency and CO2 emissions. Figure 4 shows the reading and processing data unity and figure 5 shows the gas emissions probe.

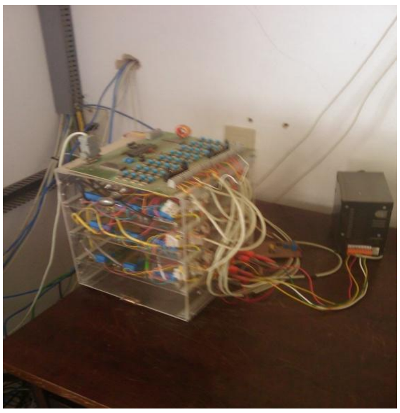

Figure 4. Reading and threating data unity

Figure 5. Gas analyses probe

The data obteined are transmitted to a computer, Pentium 4 processor which has dedicated software for the admission of the data obtained. After obtained the data, they are passed to the Excel platform and so are stored. Figure 6 shows the digital displays and figure 7 shows the computer utilized.

Figure 6: Digital displays

Figure 7: Computer

3.2. Experimental Procedure

In this experiment it is defined that the engine must work in Dual Cycle with biodiesel as pilot fuel with concentrations of B10 to B100 with 10% variation for each new procedure. Also sets up a replacement rate of 85% for the measurement obtained be considered valid.

Initially the biodiesel mixture that will be used in the experiment is prepared, being this starting at B10 and ranging until B100. While B10 mixture is ready it is put in a balance, along with your tank and other extra pounds in order to obtain a more accurate measurement of the mass variation of the fuel. All the extra weight of the balance is subtracted from calculations.

The engine is started and put under low load to get its operational stability. When acquired this stability, the load of 40 kW is imposed on the engine, and the measurement starts using the software when the next variation of pilot fuel is appreciable by the balance. So it is interrupted when happen a variation of 50 or 100 grams of pilot fuel. The data is exposed in the computer monitor and are considered valid if the replacement rate of 85% is respected. Being, these data are passed to Excel spreadsheet and organized. If don't the flow of natural gas to the engine is changed through the control software, and the test, is repeated.

After this step, the engine load is changed to 60 kW and repeats the procedure. The same is done for the loads of 80 kW, 100 kW, and 120 kW. The procedure realized for B10, for example, is repeated for other mixtures of pilot fuel. It is and experiment that take days considered the difficult of obtaining valid data. This is due to the fact that the properties of natural gas (pressure, temperature) changes vary with the variation of environmental temperature and pressure, ranging in this way, the number of molecules flowing into the same flow.

3.3. Method of data analysis

Data obtained, as said previously, are organized in Excel spreadsheet. The spreadsheet shows for each part of the experiment the values of the properties of the combustion according to the load applied to the engine. For example, the table 4 shows the data collected in the experiment with biodiesel B10. Note that the replacement rate (Rp.R.) is always close to the 85% originally laid down.

Power	Mass	Time	Consumption P. D.	Hourly consumption	Rp.R.	G.F.	CO	CO2	O2	Eff	T.E.S
Kw	Kg	Sec.		Kg/h	%	M3	ppm	%	%	%	°C
TEST 01:DIESEL WITH 10% OF BIODIESEL											
40,00	0,05	100,60	12,47	1,79	85,65	19,00	1375	3,30	13,50	68,48	320
60,00	0,05	75,60	16,57	2,38	85,63	22,30	1397	3,80	12,40	68,98	359
80,00	0,10	120,50	20,81	2,99	85,64	27,00	986	4,50	11,24	71,02	387
100,00	0,10	96,00	25,35	3,75	85,21	29,40	1124	4,98	10,30	71,88	411
120,00	0,10	86,00	29,50	4,19	85,81	31,10	1168	5,40	9,40	72,58	433

Table 4. Data collected for biodiesel B10 as pilot fuel.

4. RESULTS AND DISCUSSION

With data obtained and organized in spreadsheets, two graphs are plotted in appropriated software. One of the graphs refers to the thermal efficiency in function of the power of the engine. The second refers to the emission of CO_2 also in function of the power of the engine. Each line in the graph represents a type of pilot fuel utilized. For practical reasons it is showed the graphic lines only for mixtures B40, B60, B80, B100 and pure diesel. This last one, to be compared to the others. Figures 8 and 9 expose the graphics respectively, of the CO_2 emission and thermal efficiency.

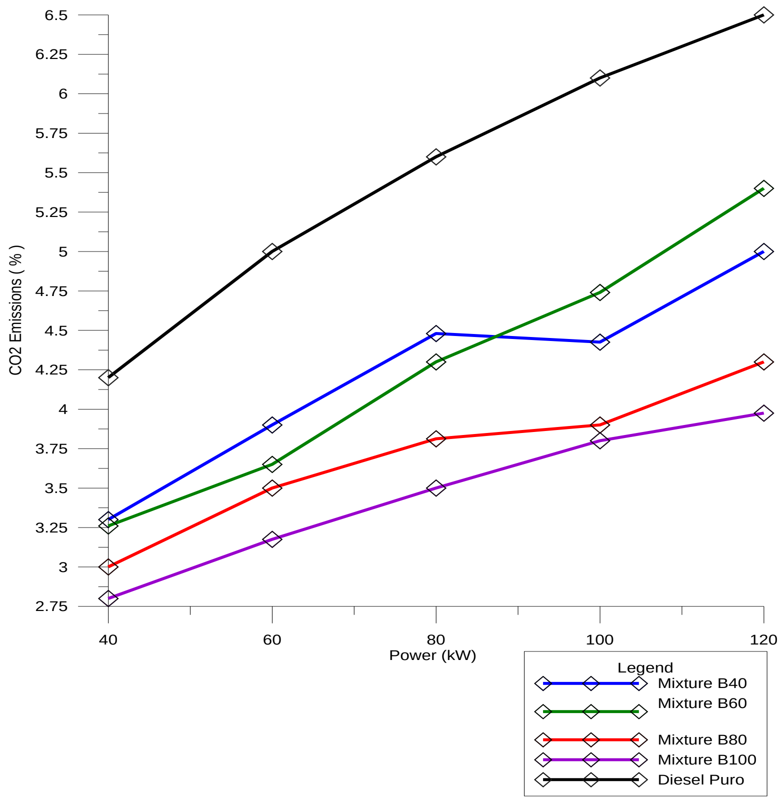

Figure 8. Graph of CO_2 emissions X Power for B40, B60, B80, B100 and pure diesel.

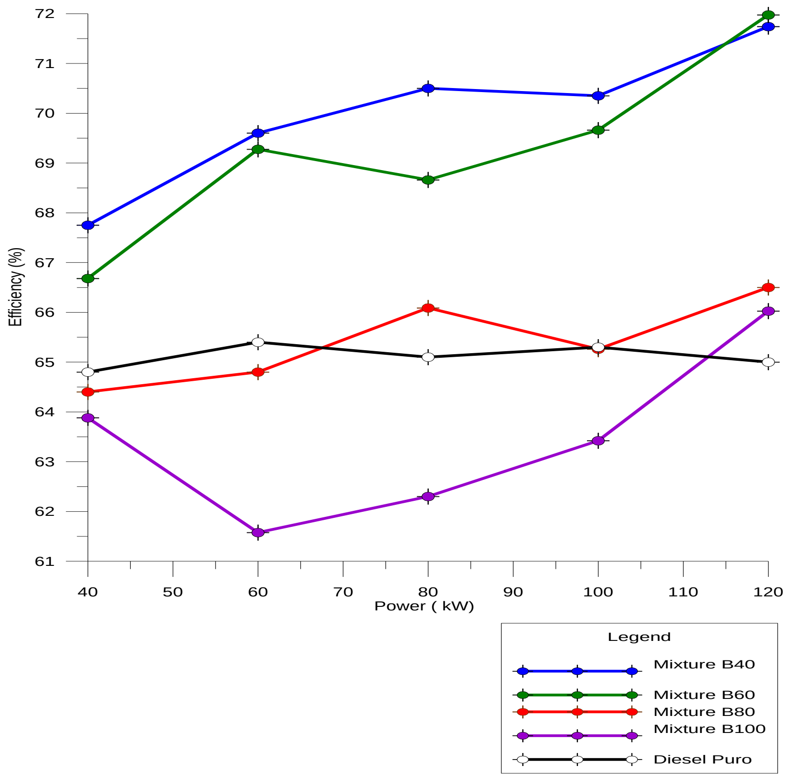

Figure 9. Graph of Thermal Efficiency X Power for B40, B60, B80, B100 and pure diesel.

Relative to CO_2 emissions, it is noted a significant reduction for all the types of biodiesel mixtures utilized when compared to the use of diesel fuel purely. In a more detailed form, it is perceptive that until the power of 80 kW, the bigger is the biodiesel concentration, the smaller is the CO_2 emission. But, for a power between 100 kW and 120 kW it is perceptible a smaller emission for B40 in spite of B60. Indeed in this case B100 still being the smallest emission fuel pilot. The bigger difference comparing to pure diesel fuel occurs to the power of 120 kW to B100 mixture, which is a 42.7% difference of concentration.

R. Uma et al, 2004, obtained the value of 6.1% of CO_2 emission in test with pure diesel with a load of 40 kW and, for Dual Cycle with the same load, obtained the value of 11%. However, the gas replacement rate was of 67% and the test did not use biodiesel as pilot fuel.

Relative to thermal efficiency of process it is noted a more complex situation. For the power of 40 kW the mixture B40 has the biggest efficiency (near to 67.5%), which is also bigger than pure diesel condition (64.8%), which means a difference of 4.16% of concentration. The mixture B40 continues being the most efficient for 60 kW, but it is noted an important increase of the efficiency of the mixture B60. For the load of 80 kW this difference back to increase followed by other approximation of these rates which is followed by an inversion at 120 kW, in which B60 has the biggest thermal efficiency calculated in 71.55%. It is noted that the condition B100 did not present satisfying results, being in almost all the situations (except to the power of 120 kW) with rates worse than pure diesel's rates.

6. CONCLUSIONS

After obtained the results and have them detailed in graphs, was noted that the pure diesel condition can be always replaced bringing benefits. Relative to the carbon dioxide emission all the mixtures of biodiesel presented considerable lower emissions, being the condition B100 the smallest. Relative to the thermal efficiency of the process, although the complex comportment, the mixtures B40 and B60 showed efficiency bigger than the situation with pure diesel. Considering efficiency and CO_2 emission together, the mixtures B40 and B60 are the most appropriated to produce electrical energy by all the conditions imposed, as long as they can reduce the carbon dioxide emissions and increase the thermal efficiency of the process.

7. ACKNOWLEDGEMENTS

This work was financially supported by CNPq. The authors would like to acknowledge the references reported in the paper that contributed for its improvement.

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