MWM D229-4 DIESEL ENGINE CONVERTED INTO A VEHICULAR NATURAL GAS OTTO CYCLE ENGINE

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Abstract. *Since 1982 natural gas has been supplying internal combustion engines as an alternative to fuel vehicles in Brazil. More recently, many dual imported kits (diesel / gas), have been used in this country. Trying to enlarge environment contribution and to reduce fuelling costs, a team from the Laboratório de Inovação at Federal University of Paraíba, LI, has converted a MWM-D 229-4 diesel engine into an Otto cycle engine using an original, simple and low price technology, which since then has operated just with Compressed Natural Gas, CNG. The present paper discusses not only the conversion principles, but it comments on the emissions and the economy data resulting from diesel replacement. Performance tests were carried out taking into account: an electrical dynamometer, a gas analyzer, a notebook, a strobe light, a tachometer and a digital thermometer. The converted engine having a conventional mixer and a dynamic injection system and fueled with CNG was tested in the range of 1000 to 2200 rpm, using increments of 100 rpm. For each revolution (rpm) the maximum power and the fuel consumption were determined. The load registered fluctuated between 14.46 kW (1000 rpm) and 38.47 kW (at 2200 rpm). Subsequently, the dynamic ignition was replaced by the static one, and the conventional mixer by a "stove mouth" mixer type. Under these conditions the speed was set at 1800 rpm. These changes caused a real improvement in the engine performance, which generated 44 kW (at 1800 rpm), i.e. a value very close to the maximum power indicated in the "ideal" curve distributed by MWM manufacturer. The used gas analyzer was certified by the National Institute of Metrology, Standardization and Industrial Quality, INMETRO, and the National Council on the Environment, CONAMA. The software used for gas analysis compares the emission rates produced by the examined engine to calculate the emission of $HC_{corrected}$, $CO_{corrected}$ and dilution factor, based on the 418/2009 CONAMA Resolution. Tests with the converted engine showed that fuel expenditure may be reduced from 11.52 % to 18.92 %. Considering the standards CONAMA gaseous emissions for CNG in engines manufactured starting from 2006, as $CO_{corrected}$ (1%), $HC_{corrected}$ (500 ppm de hexane) and dilution factor (1-2,5), all the converted engine emissions were kept within these limits. The water temperature of the cooling system remained between 78 and 83 ºC. This converting process may be applied to engines of different make, whatever their cylinder number.*

Keywords*: Vehicle, Diesel, Gas Natural, Performance, Emission Gas.*

1. INTRODUCTION

Since the 70's, the Brazilian government has begun taking steps to reduce dependence on imported oil from the Middle East. Among the measures adopted, natural gas has emerged as an alternative energy source on account of being a less polluting fuel of low cost and abundant in the country. Moreover, it can advantageous replace, other derivative from oil in almost all applications, including heavy-duty internal combustion engines.

Brazil has used the Compressed Natural Gas (CNG) since the 80s, when the government first tried to replace diesel oil in large vehicles, as a result of the oil crisis of 1973 (Prieur, 2006), (Machado *et al.* 2004). Thus, PETROBRAS together with other companies tried to develop new technologies to partially replace, diesel by natural gas, using the system known as diesel-gas (Prieur, 2006). (Such systems are characterized by the use of two fuels, one of which diesel. The combustion starts burning just diesel, and then a mixture of diesel and another fuel is used (Filho, 2005)). The results of PETROBRAS conjoint research suggested that not only the diesel gas technology, but also the diesel engine conversion to the Otto cycle engine to use 100 % Compressed Natural Gas, CNG, would be economically and technically feasible. On the other hand, efforts to reduce pollution caused by the use of diesel, the discovery of new natural gas reserves in Brazil, and imports of Bolivian gas, made Brazil, in 2002, the country having the third major fleet of vehicles running on natural gas in the world. And in 2003 Brazil achieved second place, with over 400 000 vehicles (Machado *et al.* 2004), this number quickly reached 1,394,000 vehicles running on CNG in 2009 (Filho, 2005). Despite this rapid progression, two observations can be made: 1. The national fleet in almost its entirety is comprised of light vehicles, in a clear demonstration that the main goal was not to replace the diesel (Prieur, 2006), (Machado *et al.* 2004), (Filho, 2005), (Losekann and Vilela, 2010). 2. Currently there is no "kit" diesel-gas produced in Brazil. This makes the cost of a conversion, considering the installation of cylinders of natural gas, and time usage, close to the value of the vehicle to be converted. It should also be considered that for the diffusion of diesel-gas system, it is necessary to develop national products that could be installed into the most representative engines of the national market. This circumstance may reduce the costs of conversion.

The accelerated growth of conversions performed in light vehicles by 2009, had a purely economic motivation. It was based on favorable differential price for natural gas as compared to gasoline; the cost of conversion and the guarantee of rapid investment pay-back. In an unexpected move, however, the Brazilian government, fearing a shortage of electricity in Brazil, started discouraging the use of Natural Gas (NG), either in cars or in industries, reserving it for thermoelectric plants (GÁS BRASIL, 2009). But again, from the end of 2010, several Brazilian gas companies have been trying to reverse this situation, since they know that the Brazilian production of natural gas and its stocks may overpass the amount necessary to attend the thermal plants, in case of an occasional drought or at any emergent demand. Therefore, nowadays, they stimulate the industrial and the vehiculof NG. These facts associated with the need to protect the environment makes room for the new conversions to occur in har use eavy vehicles (Brito, 2009).

This paper presents a brief discussion of the conversion of a diesel engine MWM-D 229-4 into an Otto cycle, to run with 100 % CNG, using a simple, but original technique. An appreciation of the fuel cost reduction and the gas emission analysis are also reported.

2. METHODOLOGY

The whole process conversion Diesel Engine to work with CNG and the tests involved were executed at the Laboratório de Inovação at the Technology Center of the Federal University of Paraíba, LI, as reported below:

2.1. Conversion of natural gas into diesel

In the Laboratório de Inovação at the Technology Center of the Federal University of Paraíba, LI, the conversion of a diesel engine into NG is started by withdrawing all conducts through which the diesel flows, including the injection pump. Then, spark plugs, spark plug wires and an electronic ignition system, which can be either static or dynamic, are added to the cylinder heads. In the case of the dynamic ignition type, a mechanical device designed and built by the team, called "transfer fulcrum" is installed between the distributor and the gear attached to the camshaft. Using the static type of ignition, however, the fulcrum is not necessary. The system itself finds the exact location for the ignition, via a sensor on the crankshaft, providing a more powerful detonation and burning the mixture more uniformly. A throttle body with a conventional mixer is also introduced. The mixer can be of the conventional type as used in most Otto cycle vehicles converted into CNG, or of the type “stove mouth”, which allows a faster response during acceleration or deceleration, and better air/gas mixture homogeneity. Finally a conventional natural gas kit is installed.

2.2. Material and methods

Performance tests with the converted engine were made using a load simulator, consisting of an electric generator and a group of resistors with load control panel; electronic scale; gas analyzer; notebook, strobe lamp, tachometer and a digital display to register the engine temperature.

Tests with the converted engine having the conventional mixer and a static ignition were conducted to speeds (rpm) between 1000 to 2200 rpm, using increments of 100 rpm. For each speed maximum power and fuel consumption were identified. The "stove mouth" mixer and the static ignition, were used in another test, fixing the speed at 1800 rpm. Similar experiments were made for the diesel engine.

The degree of contamination caused by the exhausted gases, was assessed by a gas analyzer from Alfatest, certified by the National Institute of Metrology, Standardization and Industrial Quality, INMETRO, and the National Council on the Environment CONAMA, both from Brazil. The Alfatest software allows the comparison between the emission rates of HCcorrected, COcorrected and dilution factor, based on the 418/2009 CONAMA Resolution. The CONAMA upper limits gas emissions for CNG engines manufactured starting from 2006 are: COcorrected (1%), HCcorrected (500 ppm of hexane) and dilution factor (1-2,5).

The condition of the mixture air/gas (poor, rich or ideal) was evaluated on the basis of the Lambda Factor, see Tab 1.

Table 1: Values of Lambda Factor

Lambda Factor	Mixtures	Excess
>1	Poor	Oxygen
<1	rich	Fuel
=1	Ideal	Does not exist

3. RESULTS AND DISCUSSION

During the tests the load applied to the converted engine has fluctuated between 14.46 kW (1000 rpm) and 38.47 kW (at 2200 rpm). Subsequently, the mixer "stove mouth" type associated with the static ignition system was installed in the converted engine, and tests were performed keeping the rotation at 1800 rpm. As a result, the measured power reached 44 kW, see Fig. 1. Testing the original diesel engine under the same conditions the maximum power output was 35 kW, see Figure 1. From these results we can infer that the curve distributed by the MWM manufacturer showing the behavior of the generated power as a function of the engine speed, from where the upper curve in Fig. 1 was constructed, is purely referential.

The water temperature of the cooling system for the converted engine varied from 78 to 83 º C. Those values remain inside the recommended range for Otto cycle engines.

The maximum noise intensity emitted from the diesel engine was 103 dB while that of converted engine was 93 dB.

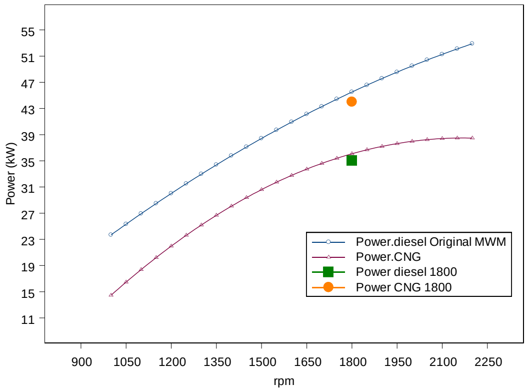

Figure 1: Maximum generated power as a function of rotation: 1. Curve derived from the manufacturer MWM 2. Experimental curve obtained from the converted engine fuelled by CNG 3. Experimental points recorded for 1800 rpm running the original diesel engine, and the converted into CNG.

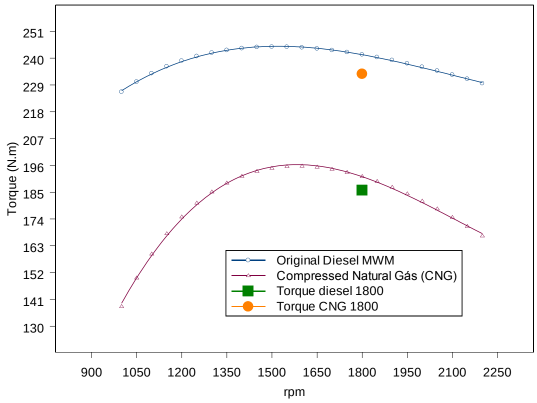

Figure 2: Torque as a function of speed (rpm): Curves and points generated from the data of Figure 1, and using Eq. (1).

Using Eq. (1) it was possible to determine the torque, for all the points plotted in Figure 1, and then to plot Fig. 2.

$$T = 9549{,}268\left(\frac{P}{n}\right) \qquad (1)$$

T Maximum torque for a given rotation (Nm)

P Maximum power for a certain Rotation (kW)

n Rotation (rpm)

Making use of the Alfatest gas analyzer, Figs. 3 to 6, showing the behavior of gaseous emissions produced by converted engine, were devise.

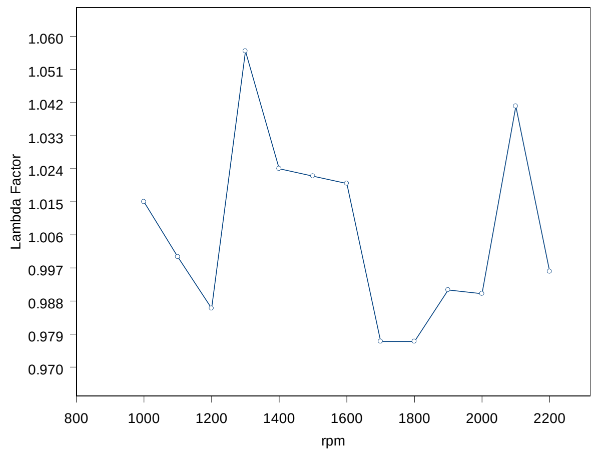

Figure 3: Curve of the lambda factor in function of the CNG converted engine rpm.

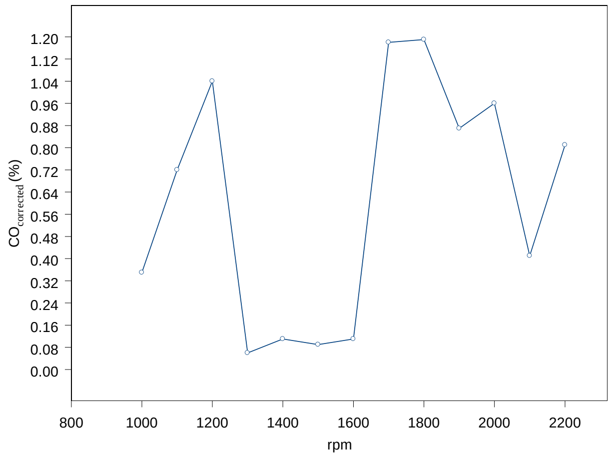

Figure 4: $CO_{corrected}$ emissions as a function of rpm, produced by the converted engine fuelled by CNG.

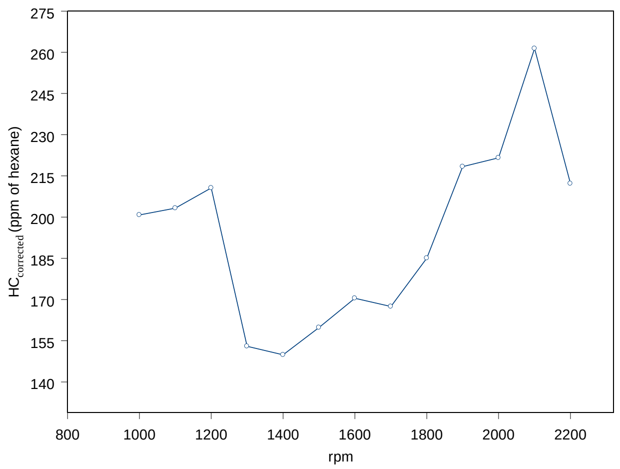

Figure 5: Hydrocarbon corrected emissions produced by the CNG converted engine in function of the engine speed.

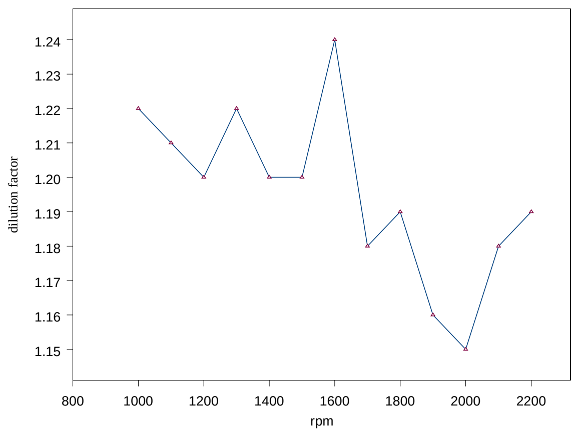

Figure 6: Dilution factor for the CNG converted engine in function of the engine revolution (rpm)

Comparing the results showed in Fig. 3 to 6, and the limits established by CONAMA, one realizes that all the gas emissions meet all the restrictions, except the CO, in some operating ranges, see Fig. 4. It was noted, however, that the points where the CO does not meet the CONAMA requirements the lambda factor is less than 1. This means that with a little adjustment in the fuel admission, the percentage of carbon monoxide can satisfy the CONAMA criteria. It is worth mentioning that all the tests were performed without using any catalyst.

3. CONCLUSION

As it has been mentioned, it was impossible to reproduce, experimentally, the correlation distributed by MWM between the maximum power data and the vehicular engine (MWM D229-4) revolution. The explanation for the fact that all the experimental data obtained using a MWM D224-4 diesel engine were smaller than the MWM released values may rest on the use of a stationary engine to simulate the vehicular one. Therefore, the curve from MWM could not be used as an effective term of comparison. On the other hand it became evident that the replacement of the conventional mixer by the “stove mouth” mixer type, and the dynamic ignition by the static one, resulted in a power of 44 kW, at 1800 rpm, very close to the corresponding point over the MWM standard curve.

Therefore, we can say from our experiments that: 1. The maximum power generated from the GN converted engine very often, surpasses the correspondent one of the diesel engine; 2. There is a reduction of fuel consumption when using the “stove mouth” mixer type, and the static ignition system; 3. The converted system may offer an enormous contribution to the environment, particularly because, in burning NG there are no emissions of particulates, neither NOx, nor SOx pollutants; 4. There was significant reduction in noise level, which declined from 103 dB to 93 dB; 5. The water temperature of the cooling system was maintained, in all tests, within the suitable temperature range, for internal combustion engines; 6. The low cost of conversion and its reliability are promising factors towards the adoption of the present technology for converting heavy vehicle engines.

4. REFERENCES

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5. RESPONSIBILITY NOTICE