ANALYSIS AN OTTO CICLE ENGINE PERFORMANCE REGARDING TO ALCOHOL CONCENTRATION IN GASOLINE AND CNG USAGE

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Abstract. *This work presents an analysis of the performance of a multi-fuel engine fuelled by gasoline, alcohol, a mixture of gasoline and alcohol and CNG. The tests are made using an four cylinder, 1.242-L, multi-fuel engine in full load, respecting the air/fuel rate established by the manufactures in the engine original calibration. In order to run with CNG, it was installed an BRC 5th generation multi-point fuel injection system. The calibration and adjustments were made using an development engine control unit for the different fuels. In this work, the performance curves are compared aiming to obtain the best relation among torque, power and specific fuel consumption for the various proposed configurations. The aim of this work is to establish the best performance and costs to the multi-fuel vehicle owner. Alcohol and CNG attained good results in relation to gasoline, showing that they are good alternative fuels.*

Keywords: *performance, multi-fuel*

1. Introduction

The increasing demand for multi-fuel cars results from the recurrent instability in oil prices and availability of alternative fuels in Brazil. This occurs due to external and internal factors such as Dollar exchange rate in relation to Real (Brazilian currency), the demand for alcohol production instead of sugar and the introduction of methane gas used as fuel. Car manufactures have been developing multi-fuel engines, adapting their engines to work with various types of fuels in order to attend to this demand.

In Brazil, the most common fuel for passenger cars is gasoline followed by alcohol. Brazilian gasoline, also known as E25, is added with 25% anhydrous ethanol. Heavy duty vehicles are mainly fuelled by diesel oil. However, recently, there is a growing demand for CNG-fuelled engines (compressed natural gas), although these engines are not commonly sold by the industry. There are not any models originally fuelled by CNG in the market.

Alcohol and CNG are the most commons alternative fuels in Brazil. The alcohol used in Brazil, also known as E94 or hydrated ethanol, is extracted from the sugar cane and it is a mixture of 94% ethanol and 6% water. Alcohol was introduced in the market after the international oil crisis in the 1970's when the cost of oil barrel rose suddenly. Then the Brazilian government launched the PROALCOOL (Alcohol National Program). After some years, around 90% of the cars produced in Brazil were fuelled by alcohol. However, this market share decreased to less than 5% in the late 1990's.

In the middle of 1980's, aiming to find an alternative fuel to replace diesel for heavy duty vehicles, the Brazilian Government released the PLANGÁS (Natural Gas National Plan). In spite of this initial intention, it became popular with passenger cars, mainly among taxicabs due to its low price.

The use of this fuel requires an adaptation in either gasoline or alcohol fuelled engine, installing what is called "Kit gás" (CNG kit). Although it shows lower level of pollutant emissions, it shows a significant reduction in the engine efficiency since the engine does not work with the best CNG compression ratio.

When FIAT AUTO faced a period of crisis in 1980, its engineers developed a project with the proposal of production stage improvement. The result was an innovative concept of compact engines named FIRE (Fully Integrated Robotize Engine). The main characteristics of this engine are a high specific power, high torque in low speeds and high thermal and volumetric efficiencies. There was also an enhancement of the constructive characteristics since the numbers of parts were significantly reduced and its assembly process was undoubtedly revolutionary. In 2000, this engine in its first generation, 1.3 16V, was released in Brazilian market. In 2003, a multi-fuelled FIRE engine was launched. The aim of this work is to analyze the performance of gasoline and alcohol in different concentrations and CNG in a multi-fuel engine. Although it can be simply made using the original ECU (Electronic Control Unit) and original calibration installing a BRC (CNG kit manufacturer) CNG system in the engine, it was chosen to develop an new system capable to control the engine running with all desired fuels.

2. Objetives

The objectives of this project are to configure the engine to be fuelled by E25, E94, a mixture of 50% E94 and 50% E25, and CNG, optimize the calibration to achieve the best performance, analyze the results and compare efficiency curves of a multi-fuel FIRE FLEX 1.3 8V engine. This work has a proposal to show the differences in engine performance because the multi fuel engine does not present the ideal compression ratio for each fuel and they have also particularities such as their heating values.

3. Methodology

The purpose of this work was to analyze and compare torque, power, fuel consumption and specific fuel consumption of an engine fuelled with different concentrations between E25 and E94 and also fuelled with CNG for the same compression ratio of 11:1. A pollutant emission analysis will be done in a further work and compared with the results obtained from this project. All the ECU calibrations were made using a MoTeC ECU. The MoTeC calibrations follow the fuel/air proportion of the original ECU calibrations that were obtained previously.

The fuels used were 100% E25, 100% E94, a mixture of E25 and E94 with 50%-50% proportion and CNG. Each fuel has its own properties related to physical and chemical characteristics as heating values, molecular weight, stoichiometric air-fuel ratio and ideal compression ratio.

In order to develop this work, some partner companies have provided a significant contribution, supplying a great part of the systems and components needed such as engine, linear lambda sensors, flow meter and fuel. The other essential items were bought like a CNG multipoint system and the MoTeC electronic control unit.

3.1. Preliminary stages

Before going to the dynamometer, some preliminary stages were necessary. These stages have already been described previously by Baêta (2004a).

After these preliminary stages the MoTeC was chosen as the best option for this work since it allows setting the system to operate with any kind of fuel and combustion engine. All the procedures, including programming and adjusting can be done using this ECU. The main MoTeC specifications are described as:

- Microprocessor 32 Bit 33 MHz;
- Manufacturing Standard IPC-S-815-A Class 3 High Reliability;
- ECU Control Software in FLASH memory;
- Cylinders up to 12;
- Engines 2 stroke, 4 stroke, rotary (1-4), odd or even fire;
- Maximum 15,000 rpm;
- Injection time accuracy 10 ms;
- Ignition timing accuracy 0.25 degrees;
- Boost control;
- Internal Temperature Range -10 to 85 °C;
- Ambient Temperature -10 to 70 °C;
- Operating Voltage 6 - 22 V DC;
- Operating Current 0.4 A Maximum.

Additional information could be found at MoTeC Internet site.

3.2. Test stages

The first part of this work was to obtain the performance curves of the engine fuelled by E25. The engine was set with the original configurations, using an IAW 4AF.FF ECU (original electronic control unit model). The acquisition process of the whole performance curves in this work is in conformance with NBR ISO 1585 standard. The engine was installed onto a hydraulic bench dynamometer (Fig. 1) with the original system (ECU, body computer and other components). It was also interlinked with EDI (engine diagnosis software) software, instrumented with a linear lambda sensor, thermocouples along the intake and exhaust systems, barometric sensor, humidity sensor and room temperature sensor. In sequence, the break in process was performed in order to prepare the engine to the tests. Afterwards, the engine performance curves (torque, power and specific fuel consumption) were acquired for E25. The measurement of the fuel consumption was made timing the consumption of a measured mass of gasoline.

To begin the second part of this work, the original control system was retired and replaced by the MoTeC ECU and its harness. Also, the CNG multipoint injection system and its components except its ECU were installed and adapted to be controlled by the MoTeC system. The installed CNG multipoint injection components were:

- CNG filter;
- CNG pressure regulator;
- CNG injectors;
- Tubes and other accessories;

In order to measure the CNG consumption, after the pressure regulator a flow meter in Fig. 2 was coupled to the whole system. The consumption calculation was made through an approximation of the CNG with the ideal gas model. CNG composition, necessary to calculate the relative molar mass, with the percentage of its components, was provided by GASMIG

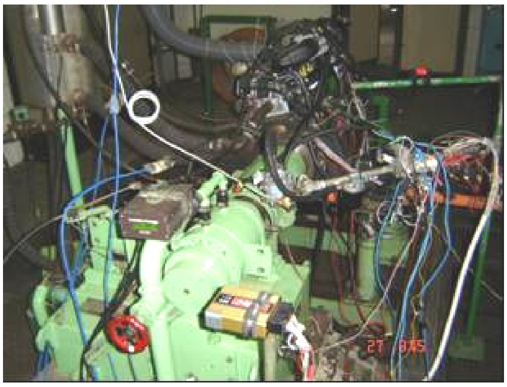

Figure 1. engine on the bench dynamometer

Figure 2. CNG Flowmeter coupled to system

Then, the MoTeC software was initially configured for this stage. The first part of this configuration was setting the characteristics of the engine, injectors and sensors.

After, for each fuel , E25, E94, blend and CNG respectively, all the stages described below were executed:

- Calibration and adjustment of the ECU;
- Performance curves data acquisition at WOT, including torque, power, fuel consumption, specific fuel consumption and lambda values;

The followed mapping procedure in this work is described by Baêta (2004b) except that there was not any stage which includes a turbo compressor.

The blend was a mixture of E25 and E94 in same proportion. As Brazilian gasoline, E25, is added with 25% anhydrous ethanol, the correct volumetric proportion of this mixture was around 63% ethanol and water and only 37%

For the CNG and blend of E25 and E94, the efficiency and load (EFF and LOAD) calculation were no longer a function of MAP (manifold air pressure) and BAP (barometric air pressure) values. Henceforth, these variables were set as throttle position, simplifying the calibration maps and further, the calibration.

Moreover, there were some different steps from those described by Baêta (2004b) that were adapted only to CNG:

- The “injection timing table” calibration was no longer made by calculating the specific fuel consumption point by point for each engine speed, but observing the variations in lambda value. According to this method, the richer the lambda value is, the better is fuel delivery.
- The entire fuel map was set to reach lambda value equals 1.00 independently the engine speed and engine load. Since there is no effective reduction on exhaust temperature and no significant increase on torque for rich mixture in a CNG-fuelled engine, there is no reason for setting richer lambda. So, the lambda sensor was set up in closed loop in order to improve the lambda value, and consequently, the performance curve. It was done due to little deviations in lambda values for the same injection pulse width because the CNG pressure in the cylinders varied from 200MPa to 10MPa causing change in the CNG specific volume.

4. Results and Discussion

The first obtained result data were both ignition advance map and fuel map. These maps are from the calibration of the engine fuelled by all fuels with MoTeC ECU. Other maps such as dwell time and injection timing were also obtained for this initial configuration but they are not as relevant as fuel and ignition maps in this analysis.

The fuel maps that are shown in Fig. 3, Fig. 4, Fig. 5 and Fig. 6 are presented in percentage of IJPU (% IJPU). IJPU is the maximum time of the injector pulse width. The value in the map represents a percentage of this maximum time. Then although the range of percentage values in the maps are near among them, they do not represent the same value because each fuel has an IJPU value. The IJPU time for each fuel is demonstrated in Tab. 1:

Table 1. Injection time table according to each fuel

FUEL	**IJPU (ms)**
Gasoline E25	15
Alcohol E94	20
50% E25 – 50%	20
GMV	10

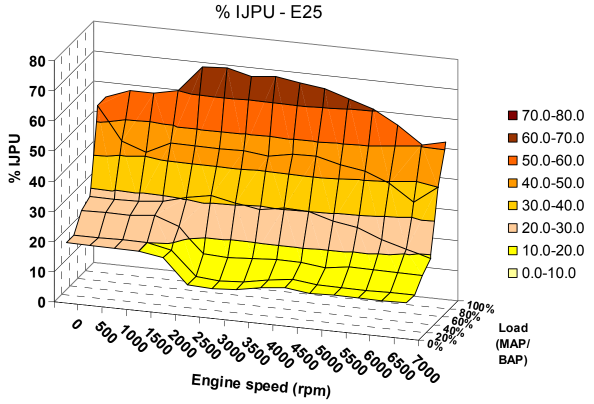

Figure 3. E25-fuelled engine fuel

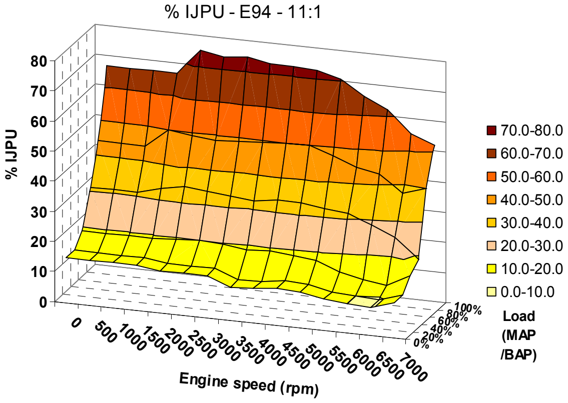

Figure 4. E94-fuelled engine fuel map

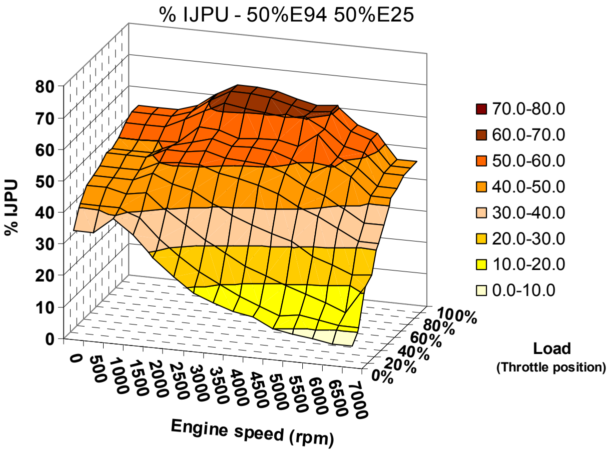

Figure 5. 50%E94-50%E25-fuelled engine fuel map

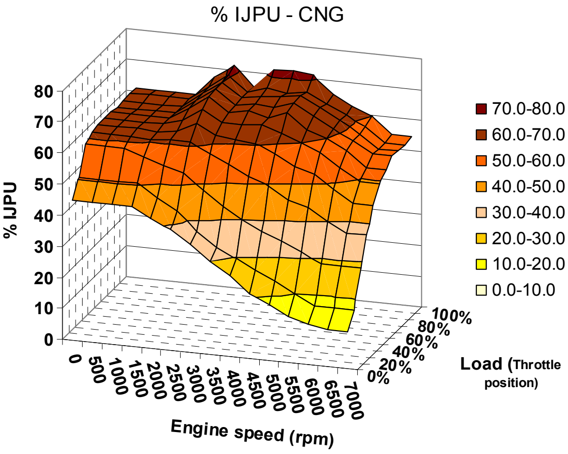

Figure 6. CNG-fuelled engine fuel map

Regarding the fuel maps in Fig. 03, Fig. 04, Fig. 05 and Fig. 06, it is easy to verify that the more the fuel is added with E94, the longer the injector pulse width time is. It is caused by the lower stoichiometric air-fuel ratio of ethanol of 9 kg air / 1 kg fuel. The opposite happens to CNG due to its higher stoichiometric value of 17.2 kg air /1 kg fuel.

The ignition maps are presented in Fig. 7, Fig. 8, Fig. 9 and Fig. 10. The calibration of the ignition advance map was obtained trying to reach either LKL (Lower Knocking Limit) or MBT (Maximum Break Torque). The engine worked with a compression ratio of 11:1 which is lower than either CNG or E94 compression ratio. According to the ignition maps, the more the fuel is added with E94, the higher the ignition advance is. Due to this fact and the higher octane number of them, in this case, the values for E94 and CNG were set by reaching MBT, since it was not found any knocking. For the mixture of E25 and E94, both LKL and MBT were used, but the higher concentration of E94 increased the ignition advance values.

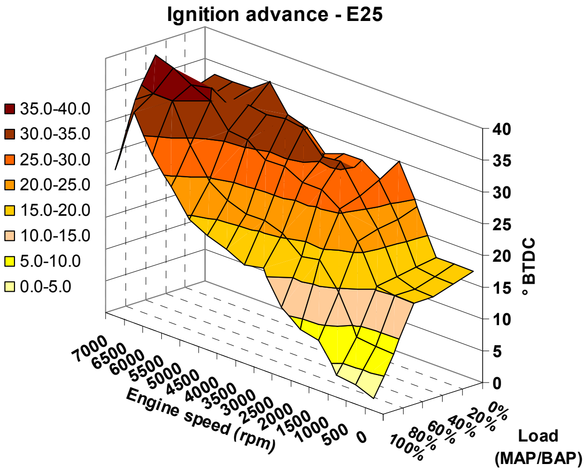

Figure 7. E25-fuelled engine ignition map

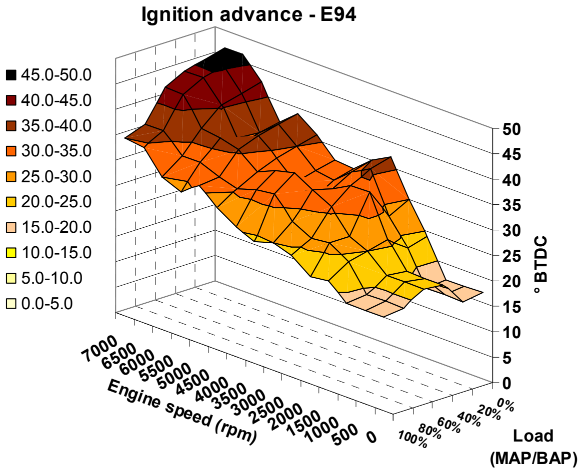

Figure 8. E94-fuelled engine ignition map

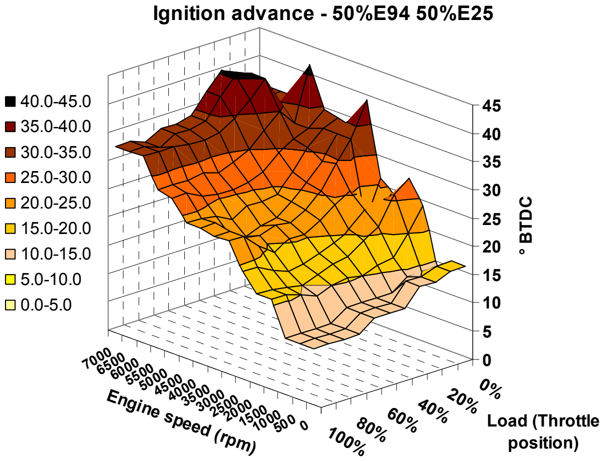

Figure 09. 50%E94-50%E25-fuelled engine ignition map

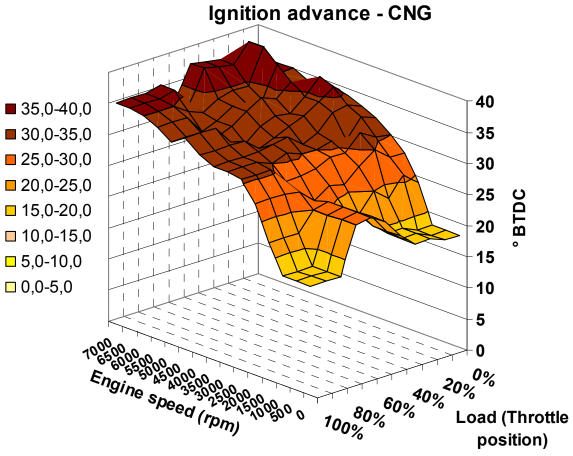

Figure 10. CNG-fuelled engine ignition map

Fig. 11, Fig. 12, Fig. 13 and Fig. 14 present the torque, corrected power, fuel consumption and SFC curves respectively that were obtained from the tests. The obtained results revealed the differences in torque, power and SFC among the used fuels. Despite the lower enthalpy of combustion, the lower air-fuel ratio for E94 means that the chemical energy released per kilogram of stoichiometric mixture burnt during combustion is greater than E25. Consequently, it was expected that E94 had better results than the others. The torque and power results which were demonstrated by the corrected torque graph in Fig. 13 and corrected power graph Fig. 14 showed that the concentration of E94 influences significantly on engine performance. Performance gain graph in Fig. 15 showed firstly that CNG performance is around 15% lower than E25 and secondly that E94 is around 8% higher than E25 in low and medium revs.

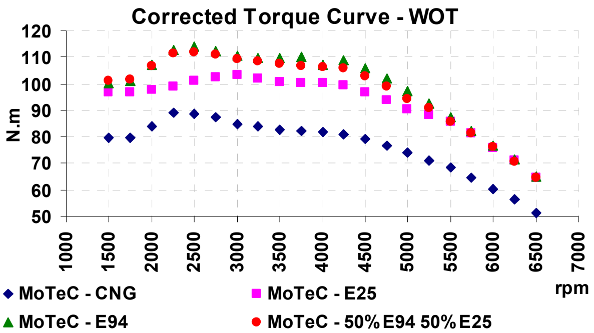

Figure 11. Corrected Torque Curves with the compression ratio of 11:1 in WOT.

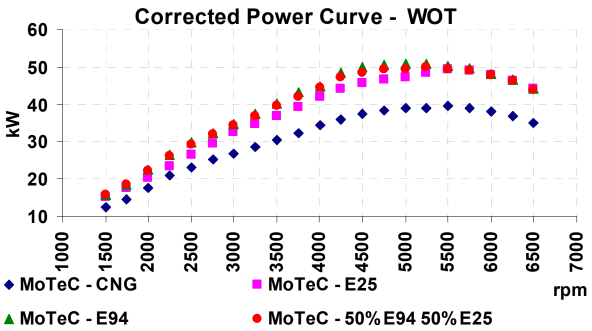

Figure 12. Corrected Power curves with the compression ratio of 11:1 in WOT.

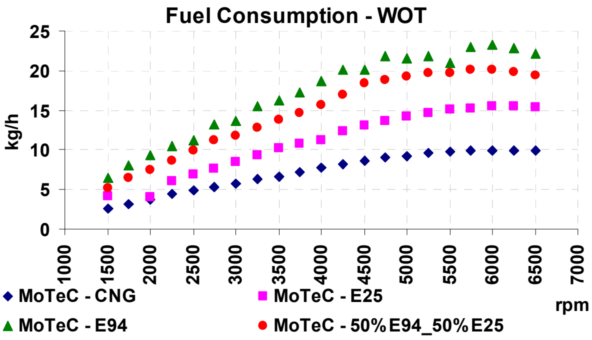

Figure 13. Fuel Consumption Curves with the compression ratio of 11:1 in WOT

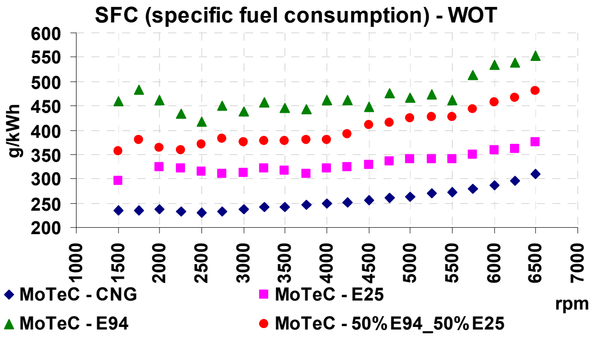

Figure 14. SFC Curves with the compression ratio of 11:1 in WOT

Figure 15 shows the performance gain of the alternative fuels comparing to E25. Since E94 stoichiometric air fuel ratio is lower than E25 and CNG stoichiometric air fuel ratio, it was expected that E94 fuel consumption was higher. According to SFC graph CNG has a better SFC if compared to the other fuels, but it is important to point out that the density of CNG is significantly lower than theirs due to the fact that the former is gas and the others are liquid. Lastly, Table 2 shows the uncertainties measured in this work

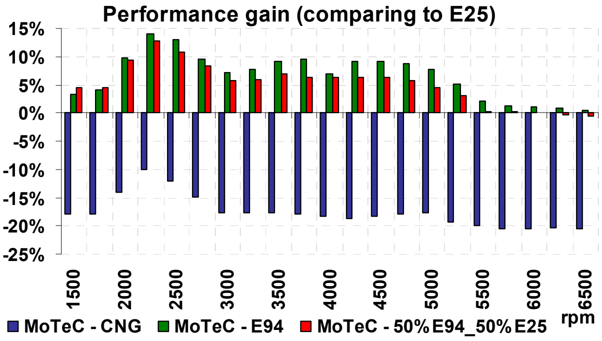

Figure 15. Performance gain comparing to E25

Table 2. Uncertainty table

Uncertainty	
Engine speed	± 40 rpm
Corrected Torque	± 1.1 N.m
Corrected Power	± 1 kW
Fuel consumption	± 0.4 kg/h
SFC	± 13 g/kW
Performance gain	± 1 %
Fuel consumption gain	± 1 %
Volumetric efficiency	± 2 %

5. Conclusion

In this analysis, the best performance results were attained using 100%E94. It is easy to verify that in intermediary engine speeds this fuel shows the best results, although the fuel consumption is higher. Otherwise, when it comes to SFC, the best results were using CNG, justifying that its use is economically feasible.

This work has the objective of providing data to develop a multi fuel engine proposed by Baêta (2004a). Comparing and analyzing the results it is possible to see that some fuels like CNG and E94 could have better results. However, in this case, they do not present the best performance that can be achieved because of the lower compression ratio which reduces torque and power and increases specific fuel consumption. This permits to develop a new system which can get better results from the CNG fuel such as using a turbo compressor to increase the engine internal pressure in order to attain its peak efficiency as proposed by Baêta (2004a). As alternative fuels such as E94 and CNG present lower costs and can offer greater performances when they are better used, they offers various advantages to the final costumer who can profit from a better use of them.

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