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EXPERIMENTAL ANALYSIS OF THE INFLUENCE OF AUTOMOTIVE AIR CONDITIONING IN FUEL CONSUMPTION IN LIGHT DUTY VEHICLES

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Abstract. *Automotive air conditioning (A/C) system causes higher fuel consumption in a car. In Brazil, emissions and consumption tests are performed in laboratories in exhaust emission benches equipped with roller dynamometers, running in driving cycle (FTP-75 for urban or HWFET for road cycle) with the A/C off. Due to the higher fuel consumption in vehicles with A/C on, the test procedure described in Brazilian standard for the urban cycle (ABNT NBR 6601) simulates its influence by adopting the procedure of increasing 10% in all the coefficients of the equation that correlates resistive force with speed. That equation is obtained from track deceleration data and it is fed into the dynamometer control system. The purpose of this work was to measure the behavior of fuel consumption of two vehicles equipped with A/C through laboratory tests, running the FTP-75 cycle to evaluate if that 10% increase is a good estimation of the A/C effect. The results obtained in the experiments yielded a fuel consumption rise in the range of 15% to 19% with the A/C turned on, against only around 3% for the ones using the plus 10% on the resistive forces. Those results showed that, at least for the two car models used for this experiment (one 1.0 L, 4 cylinders and one 2.4 L, also 4 cylinders), the Brazilian standard simulation underestimates the influence of vehicular air conditioning in fuel consumption values.*
Keywords: *Vehicle emissions, Fuel consumption, Automotive Air Conditioning.*

1. INTRODUCTION

The number of cars in Brazil increased from over 24.5 million in 2001 to 50.2 million in 2012 (Observatório Das Metrópoles, 2012). In the year 2016, the national fleet reached 51.3 million vehicles (IBGE, 2017). Some consequences are mobility problems and the increase in greenhouse gas emissions, in particular CO_2.

In Brazil, there are no limits for the emission of carbon dioxide in automotive vehicles. However, there is a concern in reducing it, with national wide programs such as INOVAR-AUTO and ROTA 2030. Those programs provide fiscal incentives for automakers to reduce the fuel consumption of their vehicles, investing in new technologies and testing them according to national standards (MDIC).

In Brazil, ABNT NBR 6601:2012 and ABNT NBR 7024:2014 are the main standards governing vehicle emissions and consumption tests. In these tests, the vehicle is positioned on a chassis dynamometer, with its traction wheels on the rollers. The dynamometer control system adjusts a second-degree curve correlating resistive force x speed to simulate, also using vehicle weight, the deceleration times of a respective car model obtained on flat track. In Brazil, the cycles used to measure emissions and consumption are the urban cycle (similar to North American FTP-75) and the cycle of road driving (similar to HWFET cycle). During those cycles, the exhaust gases are diluted in ambient air, their flow measured and totalized, and continuous samples are collected and analyzed. The gases analyzed in this type of test for Otto cycle light vehicles in Brazil are: total hydrocarbons, methane, nitrogen oxides, aldehydes, carbon monoxide and carbon dioxide. When ethanol-fueled vehicles are tested non-burned ethanol are also measured. Using the results of carbon-containing compounds, fuel consumption is calculated using the carbon balance method described in the above standards. For this fuel consumption calculation, CO_2 results are the far most important data.

In addition to reducing the emission of greenhouse gases, it is also important to adjust the quality of the methodologies for the quantification of these gases (Fermam, 2013). The difference in fuel consumption for tests conducted in emission laboratories and real-world data in Europe was 7% in 2001 and by 30% in 2013, with a significant increase in 2007 (Mock *et al.*, 2012). According to the author, one of the factors that caused this difference in results was the increase in the number of sales of vehicles equipped with air conditioning (A/C), since in Europe vehicles are not tested in the laboratory with the vehicular A/C on. In that continent, the vehicle emissions test does not provide specifics for vehicles equipped with air conditioning. In all tests, this accessory is kept off. There are in Europe projects for an additional cycle which would include tests with the vehicle's air conditioning on. However, there is no prevision for this new procedure to be mandatory (Mock and German, 2015).

Barbusse *et al.*, in 1998 tested in emission laboratory ten gasoline powered vehicles using European driving cycles (urban and extra-urban). Is was determined a baseline with the vehicles with air conditioning switched off and then two types of conditions were used with A/C on, maintaining the vehicle internal temperature in 20º C:

- maintaining laboratory room temperature at 30ºC, relative humidity 50% and no solar energy simulation;
- laboratory room temperature 40ºC and with solar energy simulation.

Results of those experiments showed an average increase of 31% in fuel consumption for the first condition above and an average of 38% rise at the second condition.

In Brazil, during the vehicular emission tests, the A/C is also not kept on. In order to simulate its influence during the laboratory procedure, the coefficients of the resistive force equation are increased by 10%, with the restriction of not generating a resistive power increase greater than 1.0 kW at the speed point of 80.5 km/h (MDIC, 2013). A similar procedure was adopted by the US Environmental Protection Agency (EPA), but it was criticized for not correctly considering the effect of the A/C. That agency tested vehicles with air conditioning on and it was observed a fuel consumption increase around 20% (Faiz *et al.*, 1996). Since 2008, they cancel the procedure of increasing in the resistive force coefficients and added to the vehicle emissions tests the complementary cycle SC03, which is performed with A/C on and with the ambient temperature of the laboratory at 35 ° C (DIESELNET, 2013).

Adopting a procedure for air-conditioned vehicles that does not consider the actual influence of such equipment on fuel consumption may be a barrier to the development and application of more efficient and economical air conditioning models. Furthermore, fuel consumption advertised by car manufacturers should be as close as possible to actual values in cars equipped with such as component. These facts gave a direction to identify the purpose of this research.

The objective of this work was to verify if the increase of 10% in the coefficients of the resistive force equation, which is adopted in Brazilian test standards, is a good estimate for the influence of air conditioning in fuel consumption measurement in vehicle exhaust emissions tests.

2. EXPERIMENTAL PROCEDURE

The following proposals were tested using Brazilian standard gasoline (Gasohol E22) as fuel, in FTP-75 cycle:

- Proposal 0 (P0) – Baseline: Air conditioning off and without adding 10% on the resistive force equation.
- Proposal 1 (P1) – Air conditioning turned on, with the maximum fan speed and without the 10% increase in the coefficients of the resistive force equation.
- Proposal 2 (P2) – Air conditioning turned off, with 10% increase on the coefficients of the resistive force equation (as recommended in the Brazilian standards for exhaust emissions tests on roller dynamometer).

Besides those tests with Gasohol E22 for both cars, the same experiments (P0, P1 e P2) were repeated with the Nissan March, now fueled with reference hydrous ethanol (EHR).

In this experimental research two vehicles were tested, tree times, in each proposal: A Honda Accord 2004, 2.4 L, 4-cylinder engine, automatic with 5 gears, exclusively for gasoline, equivalent inertia of 1361 kg and a Nissan March year 2015, 1.0L, 4-cylinder engine, manual with 5-speed, flex, inertia equivalent of 1134 kg. The ambient temperature of the laboratory was kept in the range of 20ºC to 25ºC in all tests. In both vehicles, the air conditioning system has opened loop control.

Two samples were sought at two extremes: A 1.0 L vehicle, due to its lower power, the use of air conditioning requires greater energy consumption on the alternator and, consequently, causes significant loss of power of the vehicle, forcing the user to use larger accelerations and lower gears. Vehicles with this type of motorization account for 1/3 of the total number of licenses in 2016 in Brazil. Vehicles with a motorization higher than 2.0 liters, such as Honda Accord, accounted for about 2% of vehicles licensed in 2016 (Anfavea, 2016). As will be seen in the section below, that different proportion of power spent by the air conditioner did not affect the results. Both models showed similar behaviors.

3. RESULTS AND DISCUSSION

The results for all the experiments can be seen in Table 1.

Table 1. Tests results of fuel economy

Sample	Accord 2.4			March 1.0			March 1.0		
Fuel	Gasohol E22			Gasohol E22			Ethanol (EHR)		
Fuel Economy (km/L)									
Proposal	P0	P1	P2	P0	P1	P2	P0	P1	P2
Average (3 tests)	11,23	9,41	10,88	14,34	12,46	13,98	9,55	8,09	9,27
expanded repeatability k=2	0,11	0,08	0,01	0,06	0,17	0,13	0,02	0,16	0,06

The differences in fuel consumption between the proposal P1 and the P2 (which is the Brazilian standard) are significant. These differences can be visualized in the graph of Fig. 1, below.

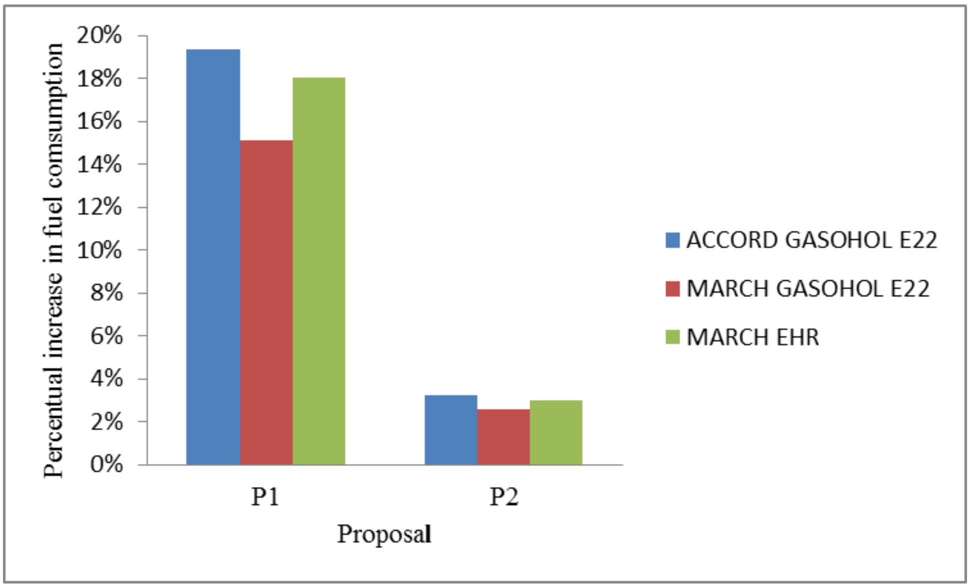

Figure 1. Increase in fuel consumption in the two alternatives of simulating A/C effect in laboratory tests

The differences in fuel economy between the proposals are significant. For the Honda Accord, which was fueled with gasohol A22, the increase in fuel consumption was 19% with the A/C on, comparing with the baseline proposal, against only 3% increase for the tests adding 10% on the resistive forces, as recommended by Brazilian standards. For the Nissan March, the tests with A/C on shown 15% extra fuel consumption with Gasohol A22 and 16% with EHR, against also 3% for both fuels using the procedure of the plus 10% on the resistive forces. Although the two cars have different characteristics, the results shown the same tendency with quite similar values. It is also important to notice that it has not been found significant change in behavior when fuel is changed.

As those experiments were done under conditions of repeatability, i.e. the same laboratory and instrumentations, pilot and similar ambient conditions, it was not declared the total uncertainty of each result since what is sought is the influence of a certain modification, in this case the use of A/C. In these comparisons, it is practical to only report the statistical uncertainty of the experiments or, uncertainty of type "A", which is the repeatability of the mean, which characterizes the dispersion of the measurements. The standard repeatability of the mean is calculated by the standard deviation divided by the square root of the number of experiments (in this case, 3). For expanded repeatability, the coverage factor k = 2 was used, which, for a normal distribution, corresponds to a 95% coverage probability of the cases (GUM, 2008).

4. CONCLUSIONS

According to the results of the present study and data from the literature review, the 10% increase in resistive force coefficients, as recommended by the Brazilian standard, is not a good simulation to measure the influence of air conditioning on fuel consumption. These results point out the need for further studies in this area, with different automotive air conditioning technologies, like closed loop control, to verify if this deviation from the ABNT NBR 6601 standard is confirmed, to implement legislation in Brazil that is closer to reality.

These results should also be used to reflect on the objectives of programs like INOVAR AUTO and ROTA 2030. The technological advances made to develop more economical air conditioning models will not be measured in the vehicular emissions tests since they are not connected during the tests. The efforts of the automakers for more economical vehicles are all focused on the results that can be measured in emissions tests, because it is through these tests that the consumption data of the vehicles participating in the program are determined. What cannot be perceived in these tests has no great incentive to be developed. In this process, the environmental control policies also lose efficiency by not being measured what is actually released of pollutants and greenhouse effect gases in the atmosphere when the automotive air conditioning is on.

Finally, it is important to emphasize that studies aiming to include all the vehicle items which influence fuel consumption is of vital importance so that the improvement of national legislation can promote the technological development through tests closer to the reality of the routine use of a vehicle by its owners.

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6. RESPONSIBILITY NOTICE

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