Experimental Study of the Energy Efficiency of Cars

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Abstract—**This article presents the problem of establishing the energy efficiency of cars, by considering both their power performance and fuel consumption. The study is based on experimental data obtained from tests of cars equipped with on-board computer and embedded transducers.**

Index Terms—**internal combustion engine, fuel consumption, engine diagnosis, dynamic performance.**

I. Introduction

Nowadays, the car is one of the most representative mechatronic products, an excellent example of integrating mechanical, electronic and informatics components software. From the beginning until today, the car has revolutionized transportation and concentrated the most significant engineering efforts to continuously improve its performance.

Among the main requirements imposed on cars, there are those relating to their dynamics and fuel saving; usually, these two requirements cannot reach the desired, maximum level simultaneously. In the specialty literature, the study of dynamics and fuel saving are performed separately from each other, without resorting to the interconnections between them.

II. Simulation Configuration Steps

In specialty literature, the references of dynamics include only the start-up, that is, the accelerator start-up time and space. Broadly speaking, dynamics refers to the whole movement, given the fact that dynamics represents any variation in time.

Similarly, in the classic sense of specialty literature, the references of fuel saving refer only to fuel consumption, expressed in various forms. Broadly speaking, we should inquire about other issues, for example those relating to the use of fuel energy input for the engine efficiency, for propulsion, etc.

Lately, the problem referring to the increase of energy efficiency in a car has been raised more and more often, and it aims at the interrelation of dynamics and fuel saving [1-3]. In other words, one does not want a high dynamic energy without considering the effort to get it; for this reason, the main efforts are directed towards improving the economic efficiency more than towards improving the dynamics, obviously because of the limited oil resources. This effort is understandable, given the fact that the car is a means of transport with very low efficiency, wasting a lot of energy introduced as fuel.

Efforts aimed at improving energy efficiency target fuel saving and dynamics simultaneously, but in one sense: they lower fuel consumption by affecting the imposed dynamics limits. In this regard, recent studies and research in this area operate with the concept called ERFC (Emphasis on Reducing Fuel Consumption) with a quantitative expression that signifies what percentage of dynamic performance is sacrificed for fuel economy [1]. ERFC criteria value is determined by the relationship:

$$\text{ERFC} = \frac{C_c - C_r}{C_c - C_p} \tag{1}$$

where: C_c [ml] – current fuel consumption, C_r [ml] – achieved fuel consumption, C_p [ml] – potential fuel consumption (possibly reduced).

For example, if we want to reduce fuel consumption in 2035 to 62.5% of the current value by sacrificing dynamic performance by 50%, (1) is made of relative fuel consumption:

$$C_r = C_c - \text{ERFC}\left(C_c - C_p\right) = 1 - 0.5\left(1 - 0.625\right) = 0.8125 \tag{2}$$

as can be noticed in Fig. 1 [1].

As stated, the ERFC size is actually a criterion for energy efficiency because fuel economy is based primarily on reducing the dynamics of the car.

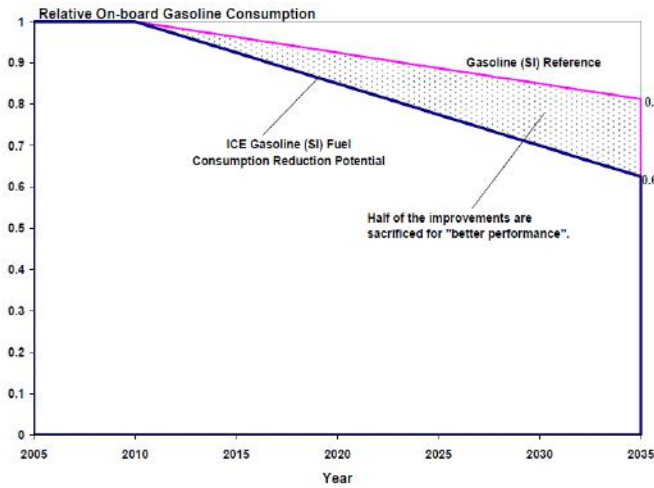

Figure 1. Consumption calculation by implementing ERFC criteria

In order not to drastically affect the dynamics, the car building companies will have to improve manufacturing technologies and to adopt new constructive measures [2].

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The experts in the field believe that the significant reduction of car weight will have a big impact. For example, if it aims to achieve ERFC value of 50% (Fig. 1), the current car must weigh 10% less.

As a consequence, Fig. 2 presents the forecast for the year 2035 on the dynamics and fuel saving of a middle-class car, based on the degree of ERFC implementation compared to the current situation targeted for dynamic time starting from zero speed to 100 km/h, and for economical fuel consumption of a car per 100 km traveled [1].

Figure 2 shows that in 2035 the dynamics decreases and fuel saving increases with an increasing ERFC value. If the ERFC 2035 is not implemented, the current fuel saving remains the same, and the dynamics will be improved mainly due to decreasing vehicle mass.

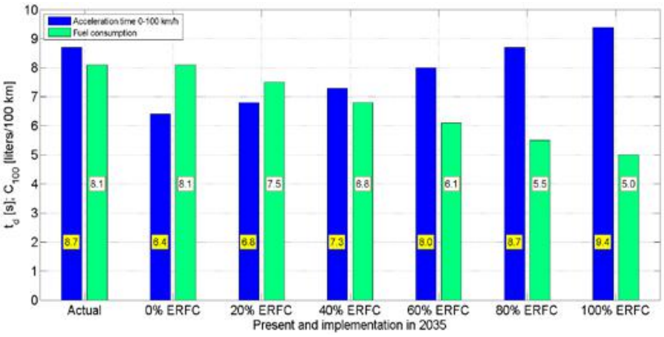

Figure 2. Forecast for 2035 for dynamics and fuel saving

In order to emphasize energy efficiency, some experimental researches were carried out on a Skoda Octavia fitted with fuel injection engine and with power plant liquefied petroleum gas (LPG), which covered most functional regimes encountered in normal operation and movement with a normal driving style. The analysis of vehicle energy efficiency was based on experimental data by defining and setting the criteria for assessing the energy efficiency and by comparing it to the two fuels using the concept of equivalent energy efficiency; these criteria should evaluate the use of quantitative energy introduced with the fuel, as well as the consequences of this use in terms of energetic plan and the factors that influence the most energy efficiency.

III. Simulation Results

The first criterion for calculating the energy efficiency is the ratio of the kinetic energy of the car and the energy introduced with the fuel [3]:

$$k_c = \frac{W_{cin}}{W_i} \cdot 100 \tag{3}$$

where the two energies are determined by the following relations:

$$W_{cin} = \frac{m_a v^2}{2}, \tag{4}$$

respectively:

$$W_i = \frac{C_h Q_i S_p}{V}. \tag{5}$$

In these expressions, the following were noted: m_a [kg] – vehicle weight, C_h [kg/h] – hourly fuel consumption of the engine, Q_i [kJ/kg] – lower heating value of the fuel, S_p [km] – space map, v [m/s], V [km/h] – vehicle speed.

Figure 3a shows the results obtained for 50 tests when the engine is running with gasoline. As can be noticed from Fig. 3c, for all these tests, 34.86% of the energy input with the fuel is actually used for driving the vehicle. The values of this ratio vary in the range 25.33 ÷ 40.73%.

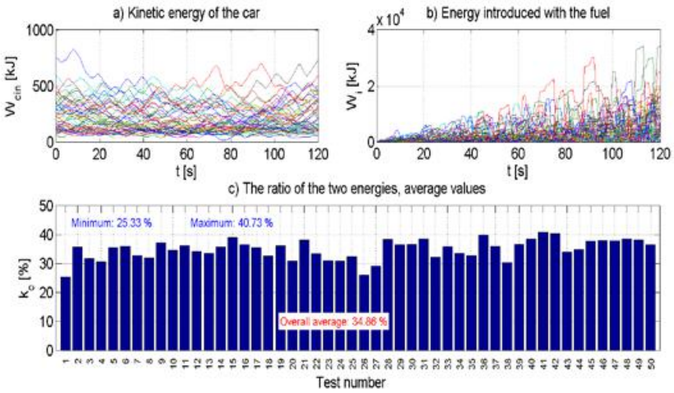

Figure 3. Criterion for energy efficiency k_c for operation with gasoline

Since (3) derives from the kinetic energy of the car, which is the effective displacement energy consumed, and the energy introduced with the fuel, it is the most important criterion in assessing the energy efficiency; this criterion has a dynamic component W_{cin} and a fuel saving component W_i.

If it uses fuel consumption per 100 km, C_{100}, then (5) becomes:

$$W_i = \frac{\rho Q_i S_p C_{100}}{100}, \tag{6}$$

where ρ [kg/liter] is fuel density.

Equation (6) is useful when in the study of energy efficiency it is desired to consider the fuel price P [lei/liter], and not only the dynamic and fuel saving elements. As noted, (6) shows two sizes which depend on fuel type, ρ and Q_i , both lower for LPG.

Figure 4 presents the results obtained for 50 tests when the engine runs on LPG. As can be noticed from Figure 4a, in all these samples 30.15% of the energy input to the fuel is actually used to move the vehicle, and the value is of 4.71% less than the value obtained when gasoline is used. Sample values of this ratio vary within the range 19.28 ÷ 37.87%.

Taking into account the price P, density ρ and lower calorific power Q_i for these two fuels, in the case of LPG we get an average equivalent relation, as shown in Fig. 4b, and calculated with the formula:

$$k_{ce} = k_c \frac{P_b}{P_g} \frac{\rho_g}{\rho_b} \frac{Q_{ig}}{Q_{ib}} \tag{7}$$

This time, as shown, the car equivalent energy efficiency increases, meaning that the average value of all tests increases to 44.13%, exceeding 9.27% of the amount of gasoline (34.86%).

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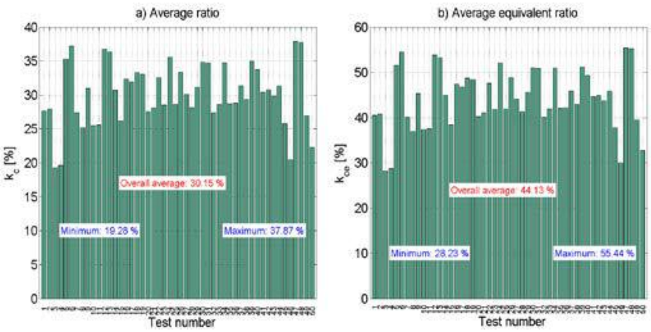

Figure.4. Mean of tests energy efficiency criterion k_c for operation with LPG

In (7) the index "*b*" refers to gasoline and the subscript "*g*" refers to liquefied petroleum gas. This equation shows that LPG is favored if we speak about price (P_b = 6.01 lei/liter; P_g = 2.85 lei/liter - on experiments), but it is disfavored if we speak about density (ρ_b = 0.74 kg/liter; ρ_g = 0.54 kg/liter) and lower calorific value (Q_{ib} = 47300 kJ/kg; Q_{ig} = 45000 kJ/kg): as a result, the first factor increases the equivalent ratio and the other two decrease it.

In this regard, it should be noted that if there is a LPG equivalent consumption, then consumption can be compared to that of gasoline. Equivalent fuel consumption per 100 km is calculated from an expression of this type (7):

$$C_{100e} = C_{100} \frac{P_g}{P_b} \frac{\rho_b}{\rho_g} \frac{Q_{ib}}{Q_{ig}}, \qquad (8)$$

which shows that the price of gas is a factor that reduces the equivalent consumption, and the density and lower calorific value increase it. Under these conditions, Fig. 5a shows average values of equivalent consumption of LPG/tests, compared to gasoline consumption per 100 km driven, in Fig. 5b.

As noted in Fig. 5a, equivalent to LPG consumption for the all tests is 7.7 litres/100 km, compared to the value of consumption of 11.3 litres/100 km during the experiments. In addition, it is noted that the two graphs equivalent to LPG consumption value is close to that of gasoline consumption (7.4 litres/100 km), is only 4.1% higher.

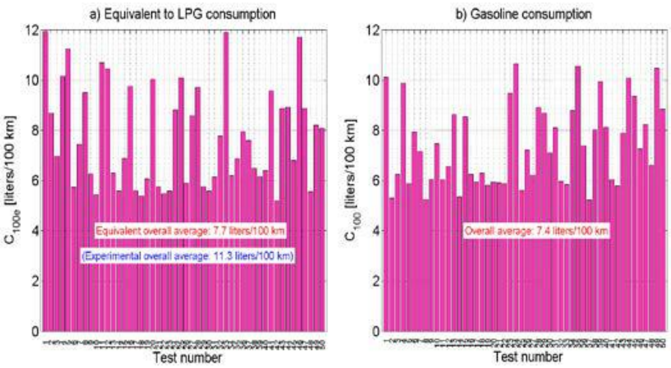

Figure 5. Fuel consumption per 100 kilometers on petrol and LPG operation

The second criterion for the calculation of energy efficiency is the ratio of energy introduced with fuel and the distance traveled by car:

$$k_{ws} = \frac{W_i}{S_p} \qquad (9)$$

the numerator resorting to the fuel saving, and the denominator to the dynamics.

Figure 6 presents k_{ws} ratio values for both fuels, and it appears that, on an average and in the case of LPG, a fuel energy of 2.04 times higher than gasoline for the all tests is required in order to scroll through one kilometer. If in this case a ratio k_{wse} equivalent with gasoline is defined (Fig. 6b), the energy requirements per unit distance are about 1.4 higher than in LPG.

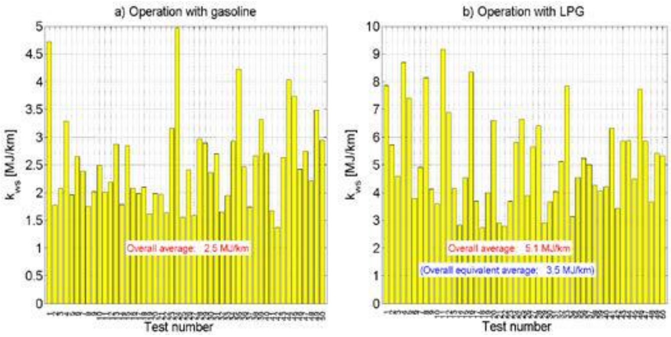

Figure.6. Average values/tests of energy efficiency criterion k_{ws}

Two other criteria for the calculation of energy efficiency are the ratio of the volumetric fuel consumption and torque M_e, and the engine power P_e:

$$k_{cm} = \frac{C_v}{M_e}; \; k_{cp} = \frac{C_v}{P_e} \qquad (10)$$

where C_v is the fuel consumption - in milliliters (ml).

In Fig. 7 are shown the average values of the last two samples for the calculation of the energy efficiency criteria for both fuels. The graphs on the left show that, in order to achieve a torque of 1 N·m, a fuel volumetric consumption increased by 74.7% is necessary for all tests in the case of LPG; if it is related to gasoline, the equivalent LPG consumption increases by 19.7%.

Similarly, the graphs on the right show that, in order to obtain a power of 1 kW, a fuel volumetric consumption increased by 58.4% is necessary for all tests in the case of LPG; if it is related to gasoline, the equivalent LPG consumption increases by 46,4 %.

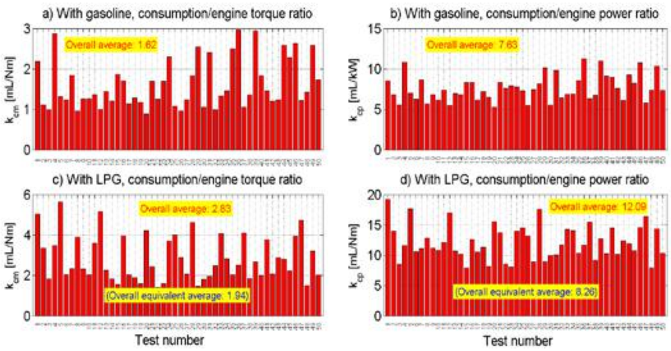

Figure.7. Average values/tests of energy efficiency criteria k_{cm} and k_{cp}

IV. Conclusion

Similarly, other criteria referring to the vehicle energy efficiency were defined and, at the same time, the influence of various factors on these criteria was examined, using the information theory.

The studies have shown that the high equivalent energy efficiency for LPG and a much lower price represent two arguments which lead to the conclusion that it is more advantageous to use LPG as fuel, compared to gasoline.

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References

[1] A. Bandivadekar and others, "*On the Road in 2035*," Report, Laboratory for Energy and the Environment, Massachusetts Institute of Technology, 2008

[2] L. Cheah and J. Heywood, "Meeting U.S. passenger vehicle fuel economy standards in 2016 and beyond," *Energy Policy*, 39, pp. 454-466, 2011.

[3] I. Copae, I. Lespezeanu, and C. Cazacu, *Vehicle dynamics.* Publisher ERICOM, Bucharest, Romania, 2006 (in Romanian)

 Digital Object Identifier 10.32754/JMT.2019.1.07