Variation of CO_2, HC, NO_X Emissions for an EURO III Engine under Urban Traffic Conditions

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Abstract: - In the experimental study were controlled CO_2, HC and NO_x emissions resulted from combustion into the engine which equips the Dacia Logan 1.4 MPI EURO III car. The experimental simulation of running in traffic conditions was performed on the LPS 3000 chassis dynamometer together with the AVL DiCom 4000 gas analyzer in order to measure the pollutant emissions. Different experimental situations in traffic operation were simulated by activating the stand LPS 3000 braking system, maintaining a constant traction F=0N and F=200N. The tests were accomplished in the Road Vehicles Laboratory from University Politehnica of Timişoara. It was noticed that high CO_2 and NO_x values were recorded in the fuel rich mixtures areas and high HC values in the poor mixtures area.

Key-Words: - pollutant emissions, chassis dynamometer, gas analyzer, vehicle, traffic conditions

1 Introduction

Road transports achieved by vehicles equipped with internal combustion engines have an important contribution to environmental pollution, practically affecting all ecosystems.

It is noted that the transport means (from motorcycles to airplanes) produce 74% CO, 61% NO_x and 21% CO2, their contribution to the particles emission being relatively small.

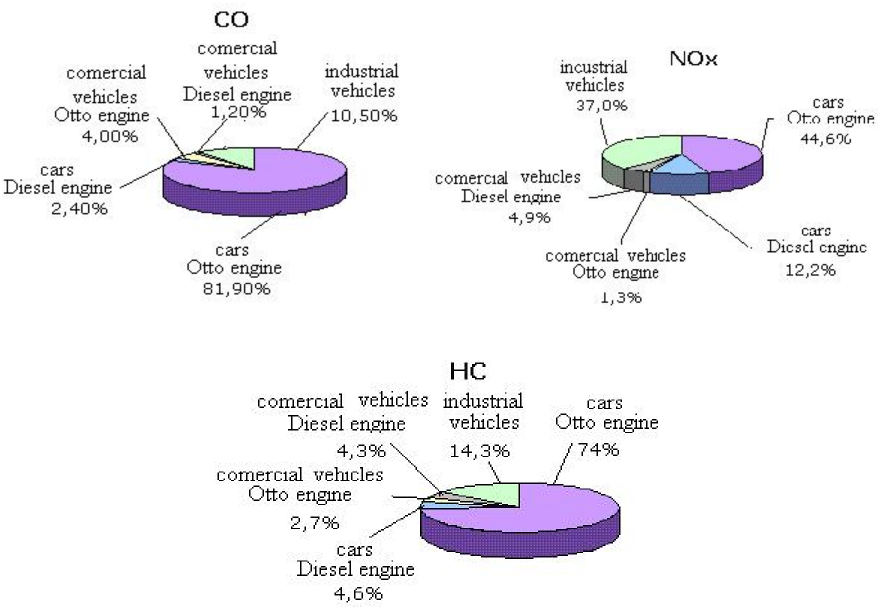

Fig. 1 Analysis of pollution in EU related to the fleet of cars
a) CO; b) NO_x; c) HC

If only pollution transport is considered (Fig. 1), it can be observed that CO and HC emissions are in particular due to gasoline engines (spark ignition engine). The particles emission is generated almost entirely by diesel engines (compression ignition engine), while the overall NO_x emission is divided relatively evenly between gasoline and diesel. As it was mentioned, the most dangerous pollution effects from internal combustion engines occur in the atmosphere through the harmful gases emission.

Compounds that are formed in the exhaust gases contribute to air pollution both globally and locally, directly or indirectly due to chemical reactions in the atmosphere [7]. The atmosphere local composition change can produce effects on the population health, such as those produced by the CO, particles and ozone emissions. On the entire planet, the increase of the gases concentration that produces the greenhouse effect, will lead to global warming, with unpredictable consequences on the environment and life.

Hydrocarbons category includes gaseous products of incomplete combustion and fuel components that can vaporize. Chemical compounds consist of many elements that exist in the fuel and which are passing unchanged through the engine. There are differences in the composition of hydrocarbons from the gasoline and diesel engines exhaust gases; generally, diesel contains a greater proportion of hydrocarbons with higher molecular weight.

Nitrogen oxides are formed through the reaction between atmospheric oxygen and nitrogen at high pressures and temperatures, specific to combustion chamber. As temperature increases, the NO_x proportion in the exhaust gases also increases. Among various oxides, NO represents the main constituent. In exhaust gases a certain amount of nitrogen dioxide, NO_2 is also present, quantity which increases when NO is exhausted into the atmosphere, by its supplementary oxidation. NO_2 is generally considered the most important for human health, therefore rules and standards are often expressed with direct reference to NO_2 and not to NO_x general category. From the proportion point of view NO_x emissions represent the second component which contributes to the greenhouse effect after CO_2 and also have an important contribution to photochemical smog formation [8].

Carbon dioxide does not play a significant role in ozone production and is non-toxic. It contributes in a 50% rate to the greenhouse effect, because it absorbs the energy radiated by the earth surface. Although is not a toxic emission, carbon dioxide, CO2 is recently considered as the most dangerous pollutant of our planet, disturbing the climate, melting eternal ice and icebergs through the greenhouse effect that it produces. It was calculated that cars exhaust into the atmosphere about 4 tones of CO_2 per year and km^2. Without taking into account the carbon dioxide role in the photosynthesis process and the action of plant chlorophyll, it can be shown that only human breath produces annually 300kg CO_2 per person which for a density of 100 inhabitants per km^2 leads to 30t per year. This means that, within acceptable limits, the car produces 12% carbon dioxide emissions, which can not currently be considered as a disaster, but can become, given the increasing motorization trends [2].

2 The Experimental Stand for Vehicle Testing

Besides standard on-board devices, measuring, acquisition and processing devices for additional data were installed in order to obtain the required information concerning the tested car quality and to record as precise as possible the test results in digital, analog, or graphics form (Fig. 2).

The correct measurement method selection, the use of the most adequate measurements, data acquisition and storage instrumentation, the most performing data processing software and the proper design of the measurement chain represent the principal condition in order to obtain reliable test results. There also have been provided optimal operation conditions of the entire measurement chain by isolation against vibration, protection from environment excessive actions, adequate voltage supply, etc [2], [6].

The testing stand achievement involved the measuring and driving conditions simulation equipment adaptation in accordance to the urban traffic. An experimental simulation method of running under traffic conditions using dynamometer testing correlated with gas analyzer for pollutants measurements was achieved.

LPS3000 permits the engine performances testing [4]. The simulation on the Chassis Dynamometer is performed with an eddy current braking system. The air-cooling fan connected to the communication console is operated by radio remote control and allows the drag simulation. For sampling the exhausted emissions during the experimental tests, AVL Dicom 4000 analyzer from the laboratory instrumentation was used (Fig. 3) [3].

a b

Figure 2 Experimental stand
a - testing equipment, b - vehicle positioning on the chassis dynamometer

a b

Fig. 3 Dicom 4000 gas analyzer
a - analyzer image; b- measurement sensors

3. LPS 3000 Software Computing Data

In "constant speed" operation mode, the dynamometer is adjusted to maintain a constant speed, irrespective of vehicle traction (from minimum to maximum throttle). Only the preset speed can be used. Eddy current braking system efficiency increases up to the maximum throttle, but not the speed.

Running conditions simulation with LPS3000 software was accomplished for the following conditions [4]:

- The power at the wheel calculation [kW].
Power at wheel has multiple links with vehicle state parameters.

$$\mathrm{P_r} = \left[\frac{\mathrm{V_t} \cdot p_0 \cdot c_i \cdot n)}{30 \cdot T \cdot R \cdot T_0 \left(1 + \lambda \cdot L_{\min}\right)} \right] \cdot \eta_i \cdot \eta_m \cdot \eta_{tr} \cdot \eta_{fr} \quad (1)$$

Where:
V_t [m^3] – The engine total cylinder capacity (volume)
p_0 [bar] – The ambient pressure
c_i [J/kg·K] – The fuel inferior heat capacity
n [rot/min] – The speed

τ [-]– The engine strokes
R [J/kg·K] – The thermodynamic constant of the driving fluid
t_0 [ºC] – The ambient temperature
λ [-] – The air excess coefficient
L_{min} [kg/kg] – The stoichiometric air quantity required to burn 1 kilo of fuel
η_i [%] – The indicated efficiency
η_m [%] – The mechanical efficiency
η_{tr} [%] – The transmission efficiency
η_{fr} [%] – The coefficient that takes into account the possible brakes power losses

- The drag calculation.

The drag calculation relation is:

$$F_x = 3{,}6\left(\frac{P_{Air}\cdot v^2}{v_{ref}^3}+\frac{P_{Flex}\cdot v}{v_{ref}^3}+\frac{P_{Roll}}{v_{ref}}\right)+a_m \qquad (2)$$

Where:
v_{ref} [km/h] – The reference speed for drag values (normally equal to 90 km/h);
v [km/h] – The driving speed;
P_{air} [kW] – The air resistance power;
P_{Flex} [kW] – The flex power;
P_{roll} [kW] – The roller resistance power;
a_m [kg] – The vehicle weight.

- The air resistance power calculation [kW]

The air resistance power is proportional to the vehicle front surface and air resistance coefficient c_w:

$$P_{Air} = 0{,}5\cdot\rho\cdot c_w\cdot A_{Front}\cdot(v+v_0)^2\cdot v \qquad (3)$$

Where:
The air density ρ = 1.1 kg/m³
The air resistance coefficient Cw = 0.38
The vehicle front surface A_{Front} = 1.7m x 1.5 m = 2.55m²
The driving speed v = 50km/h
The head wind speed v_0 = 0m/s

- The roller resistance power calculation [kW]

The roller resistance power occurs due to tire and road surface deformation as a speed function.

$$P_{Roll} = \mu_r\cdot m\cdot g\cdot v \qquad (4)$$

Where:
The tires to roller resistance coefficient μ_r=0.012
The vehicle weight m = 1100kg
The gravitational constant g = 9.81m/s²
The driving speed v = 50km/h

Since the roller resistance power represents only a small fraction of the total road load it is considered as a fixed standard value for the dynamometers in question: for steel belted radial tires the power is of approx. 2,5kW and for winter tires approx. 3,5kW. Defining the vehicle weight, aerodynamic drag power and rolling resistance power are absolutely necessary for road load simulation.

- The vehicle weight

This value is necessary in order to obtain a proportional traction force depending on the eddy current braking system from the vehicle determined acceleration.

$$F = m\cdot a \text{ [N]} \qquad (5)$$

- The torque calculation

$$M = P \text{ [kW]}\cdot 9549/n \text{ [rot/min]} \qquad (6)$$

- The engine power prediction for gasoline engines

DIN 70020 $\Rightarrow$ $K_a = \frac{1013}{p[mbar]}\left(\frac{T[K]}{293}\right)^{0,5}$

EWG 80/1269 $\Rightarrow$ $K_a = \left(\frac{990}{p[mbar]}\right)^{1,2}\cdot\left(\frac{T[K]}{298}\right)^{0,6}$

ISO 1585 $\Rightarrow$ $K_a = \left(\frac{990}{p[mbar]}\right)^{1,2}\cdot\left(\frac{T[K]}{298}\right)^{0,6}$

SAE J1349 $\Rightarrow$ $K_a = \left(\frac{990}{p[mbar]}\right)^{1,2}\cdot\left(\frac{T[K]}{298}\right)^{0,6}$

JIS D1001 $\Rightarrow$ $K_a = \left(\frac{990}{p[mbar]}\right)^{1,2}\cdot\left(\frac{T[K]}{298}\right)^{0,6}$

Where:
The correction factor K_a = 1.07671
The atmospheric pressure at the dynamometer, in mbar (1mbar = 0.001bar)
The air temperature at the dynamometer, in Kelvin degrees (0°C = 273K)
The values of these parameters are:
The ambient air pressure p = 936mbar
The ambient temperature T = 17°C = 290K

- The pressure behavior at overload

$$r = \frac{P_L}{P_E} \qquad (7)$$

- The specific fuel consumption (for 4 stroke engine) based on SAE J1349 is calculated with the relation:

$$q = 120000 \cdot \frac{F}{D \cdot n} \tag{8}$$

Where:
f_m – The engine factor
r – The pressure ratio at overload
q – The specific fuel consumption based on SAE J1349
p_L – The absolute boost pressure
p_E – The absolute pressure before the compressor
F – The fuel flow
D – The cylinder diameter
n – The engine speed

4. Experimental Results

Experimental researches were performed in the Road Vehicles Laboratory at the Politehnica University of Timisoara. In order to achieve the experimental researches, the operation of Dacia Logan 1.4 MPI-EURO III was controlled. The vehicle technical characteristics are:

- The total cylinder capacity	1390 cm^3
- The cylinder number	4L
- The maximum power	55kW
- The manufacturing year	2003
- The maximum weight	1100kg
- The maximum torque	112 Nm
- The mileage	70518km
- The ITP number	2
- The urban consumption	9.2l/100km
- The extra urban consumption	5.5l/100km
- The mixt consumption	6.8l/100km

Experimental researches are based on the control of major pollutants resulted from combustion into the engine which equips the tested vehicle.

The stand simulation of the vehicle running under urban traffic conditions was achieved by following the next steps:

- Setting the speed in constant speed module: constant and variable speed;
- Setting the force in constant traction module: F=200N;
- The air conditioned unit: turned off.

The experimental stand allows the recording of atmospheric conditions which correspond to measurements moment:

- The ambient temperature	t_a=27.8 C
- The intake air temperature	t_i=26.5 C
- The air humidity	φ=39.9%
- The air pressure	p_a=1019.6 hPa
- The steam pressure	p_s=14.9 hPa

As a result of the urban traffic conditions simulation on the test stand, the values of the vehicle emissions were recorded depending both on the engine speed and excess air coefficient (λ).

With the operating mode Constant Speed the dynomometer is regulated in such a way that the driving speed remains constant independent from the traction (from low to full throttle), i.e. only the speed which was pre-set can be driven. Only the eddy curent brake effectiveness increases up to full throttle but not the speed. A pre-set traction value activates the eddy-current brake immediately which maintains a constant traction for the duration of the measurement. The values to be set are oriented on:

- The test vehicle model and sizes;
- The desired inclination angle.

In order to run the tested vehicle up to the operating temperature an inclined surface balance was simulate. The simulated slope can be drived in any gear. Eddy current brake effectiveness remains constant at all speeds.

When vehicle runs at variable speed, CO_2 emissions shows a continuous increase under the same engine operating conditions (Fig.4). The variation of CO_2 emission values is increasing for a range between 14.5-16% when the vehicle operates on speeds lower than 2300rpm to constant speed, 50km/h (Fig 5) and after this speed value it can be observed that CO_2 emission values are almost the same.

From Fig. 6 and Fig. 7 it can be observed that HC emissions show a fast reduction up to around 2300rpm. After this speed value the HC concentrations record close and low values (between 10-20ppm).

The NOx emission variation for an continuous increasing of the engine speed shows a small increase when the speed is constant (Fig. 6) and records similar values with a small decreasing trend while the speed varies (Fig. 7).

By analysing the two cases (constant and variablepeed) it can be observed that the CO_2 emissions have similar values. For NOx and HC case, operating at variable speed leads to an increase of these emissions.

Emissions of CO and O_2 record high values at start and decrease while the engine speed decreases as it is shown in Fig.8 and Fig. 9.

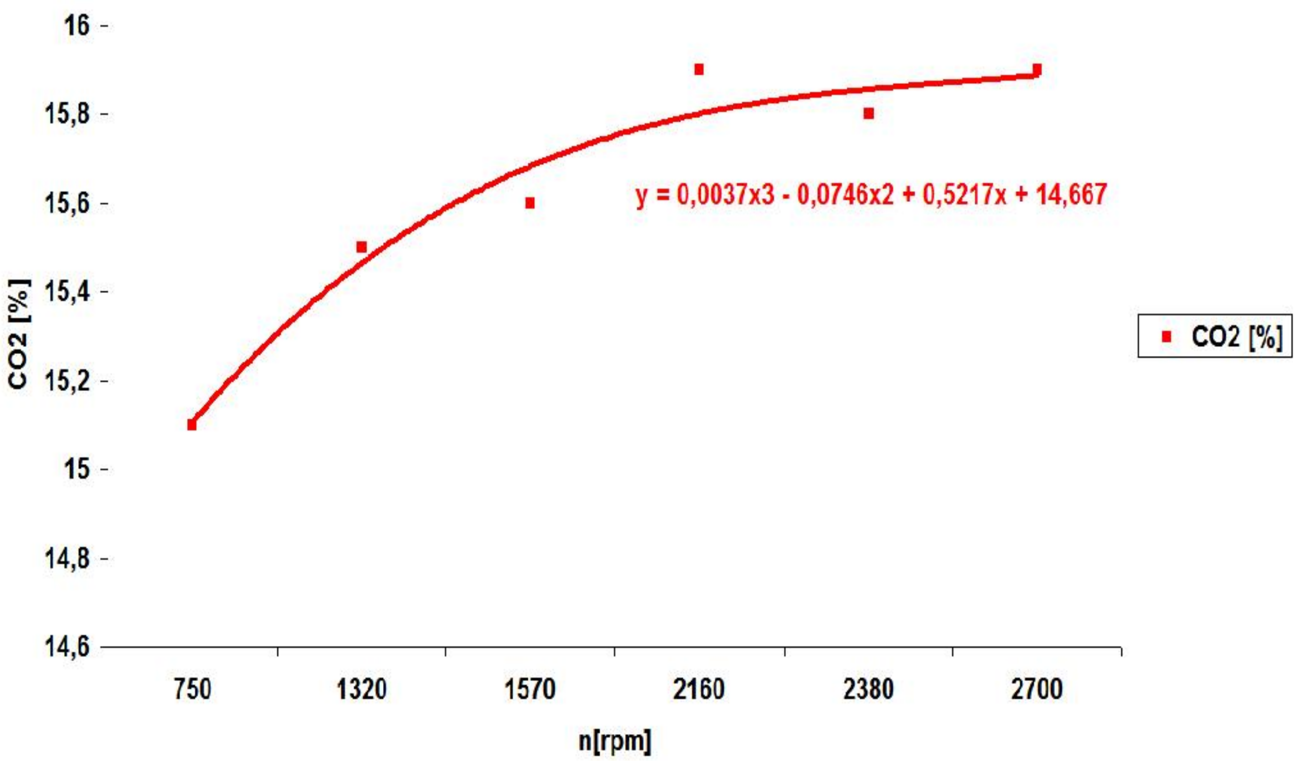

Fig. 4 CO_2 variation law versus the speed, F=200N (constant speed)

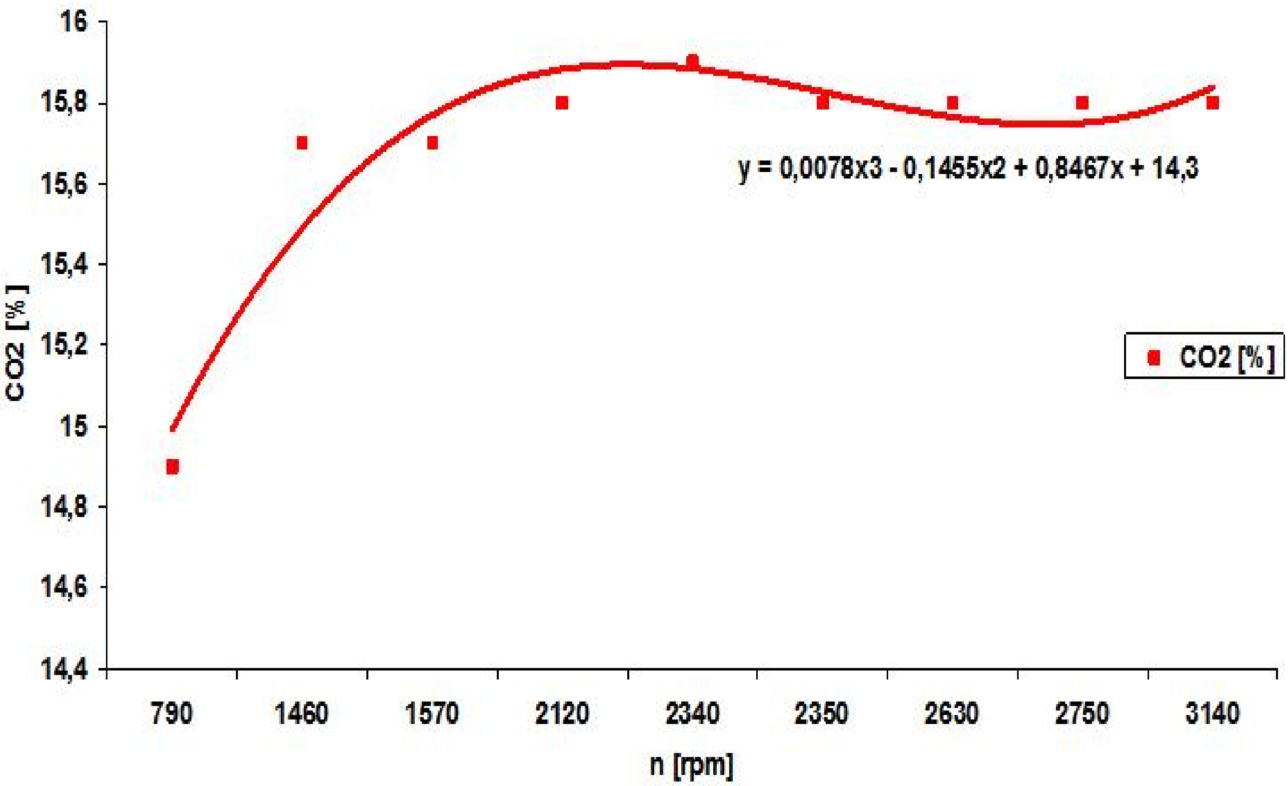

Fig. 5 CO_2 variation law versus the speed, F=200N (variable speed)

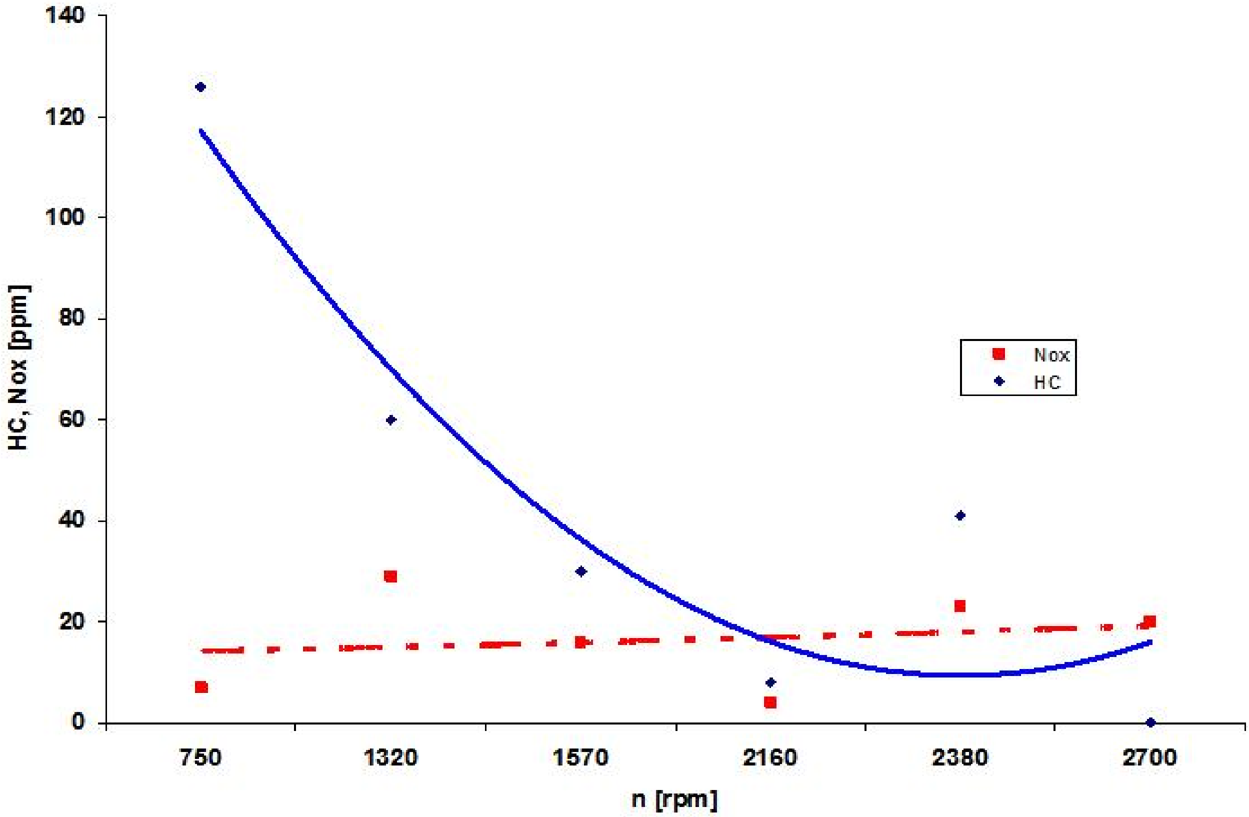

Fig. 6 HC and NOx variation law versus the speed, F=200N (constant speed)

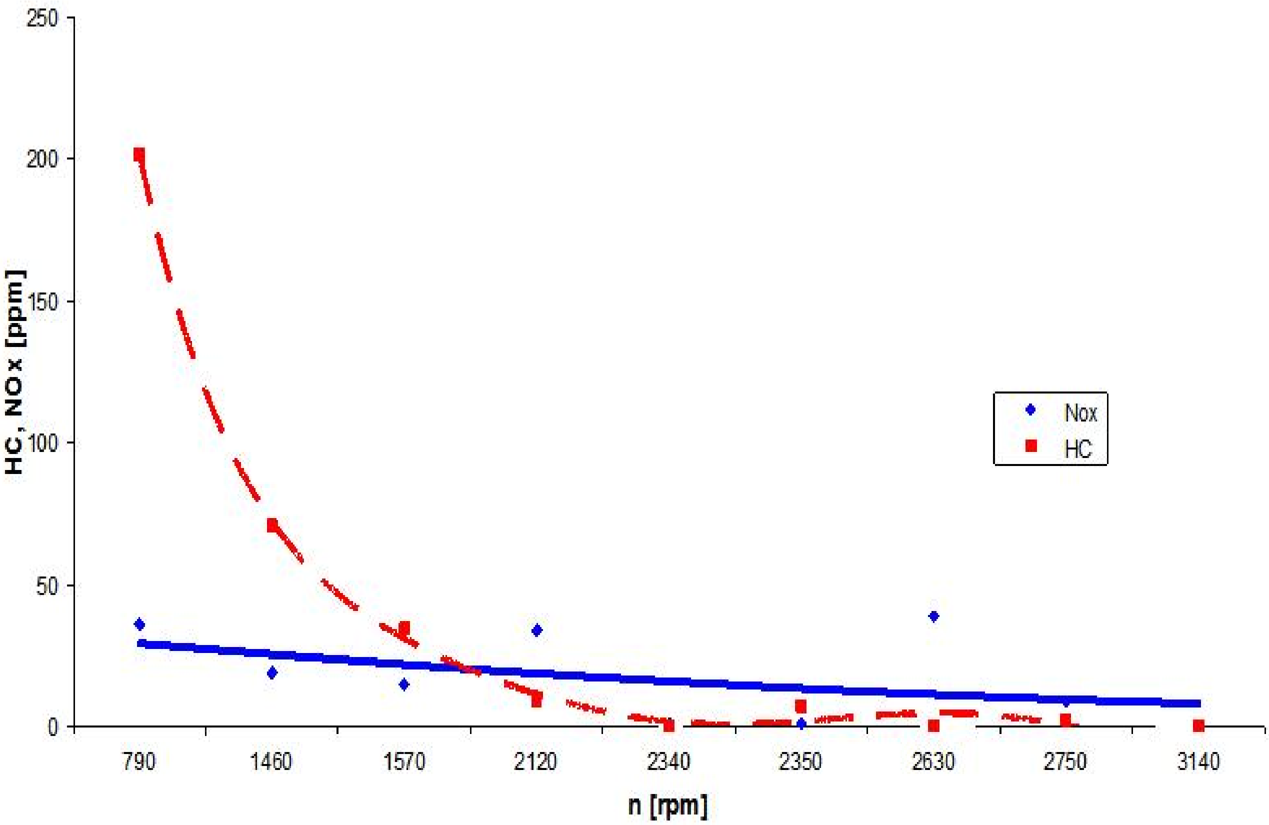

Fig. 7 HC and NO_x variation law versus the speed, F=200N (variable speed)

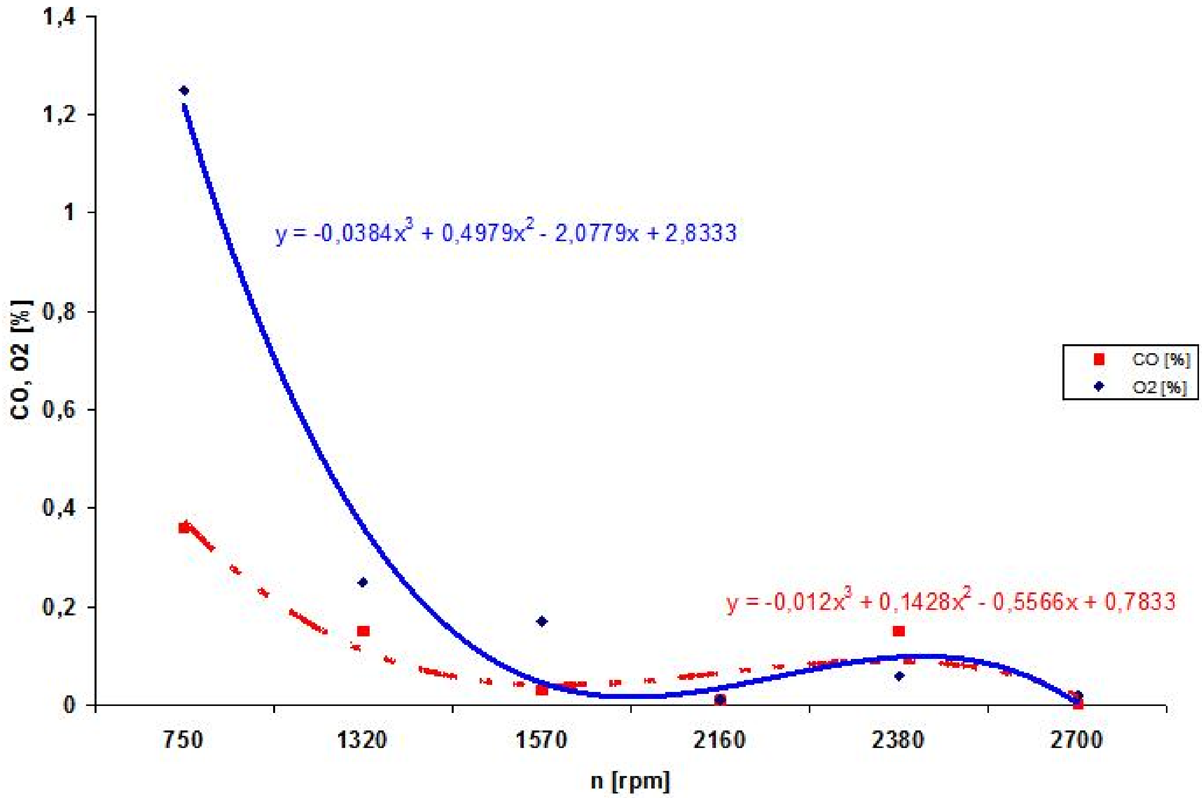

Fig. 8 CO and O_2 variation law versus the speed, F=200N (constant speed)

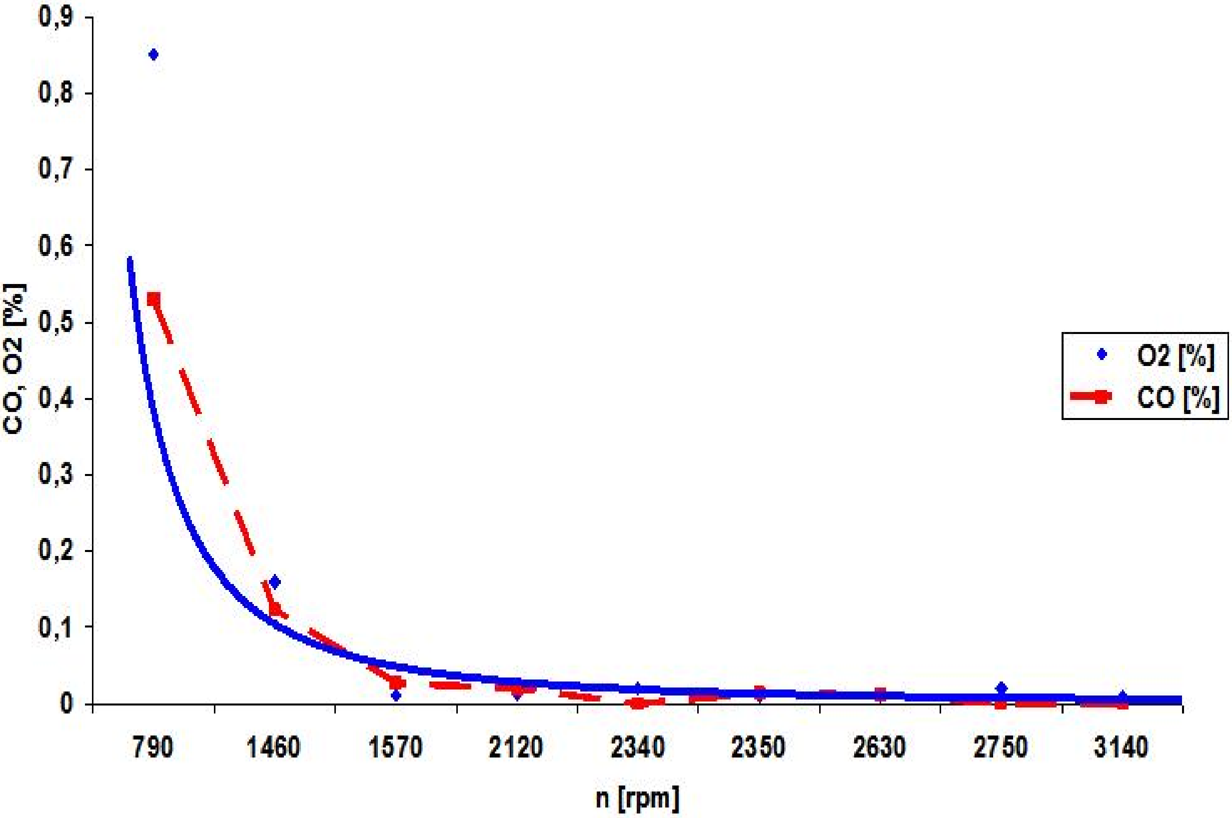

Fig. 9 CO and O_2 variation law versus the speed, F=200N (variable speed)

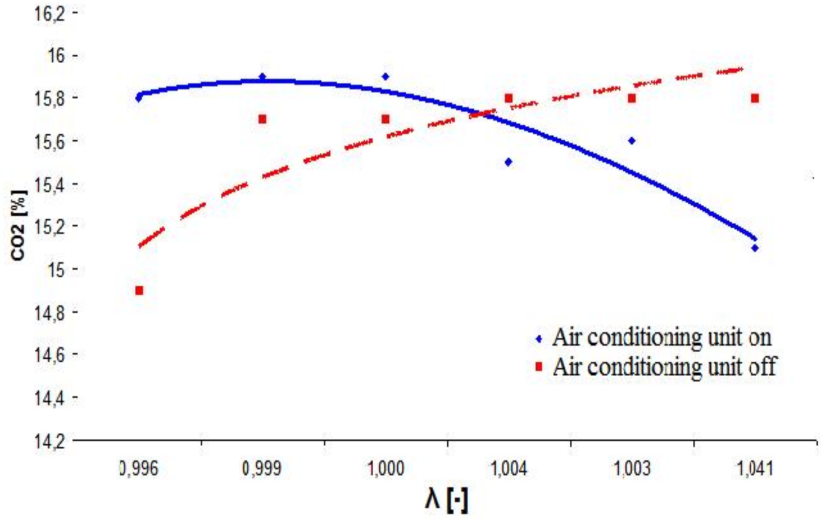

Fig. 10 CO_2 variation law versus the λ, F=200N (air conditioning unit turned on/off)

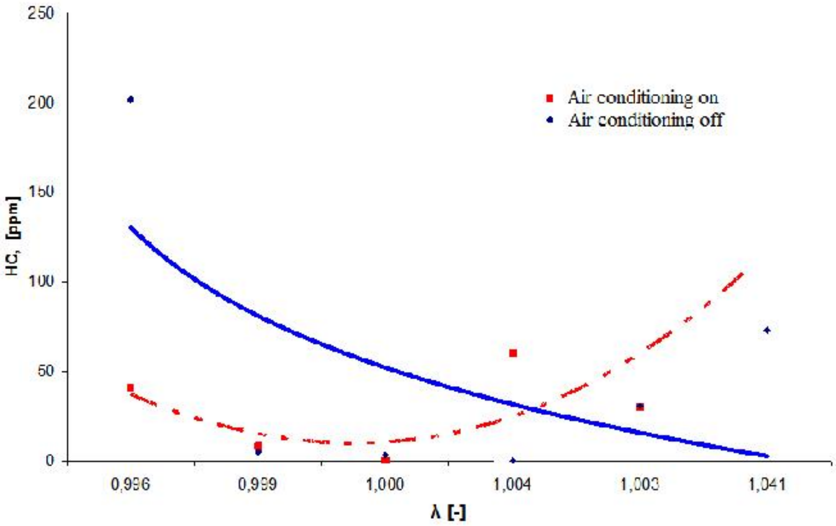

Fig. 11 HC variation law versus the λ, F=200N (air conditioning unit turned on/off)

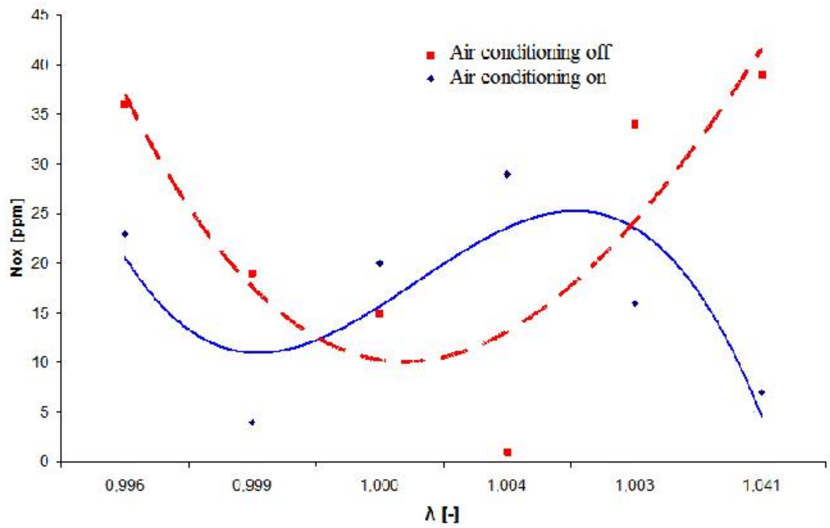

Fig. 12 NOx variation law versus the λ, F=200N (air conditioning unit turned on/off)

The LOGAN 1.4MPI vehicle running simulation on the test stand which was loaded at 200N was accomplished in order to compare thepollutant emissions for the case of air condinioning unit turned on/off.

In Fig. 10, Fig. 11 and Fig.12 were comparative plotted the variations of CO_2, HC and NOx versus the excess air coefficient for analyzing the inflence of the mixture qulity on the emissions concentration exhausted during the engine operation under traffic conditions. In the lean mixtures area, the exhausted CO_2 and NO_x are smaller due to the a smaller fuel consumption. In this mixture area values HC value increases. By the speed limitation in accordance to the urban traffic one and by maintaining the traction constant, F=200N, real traffic conditions were simulated and pollutant emissions were controlled in order to evaluate the vehicle operation for load case [1].

5 Conclusion

During tests performed on the chassis dynamometer the pollutant emission values were measured, values which are different from one operation mode to another.

It can be observed that at constant speed movement, vehicles equipped with gasoline engine are exhausting pollutants emissions at the lowest levels. By setting the speed value at 50 km/h the running conditions similar to urban traffic were imposed. The urban traffic can not provide moving at constant speed, thus for urban traffic remains to exploit the vehicle in the most polluting operation modes. The start off and idling operation modes were used in order to simulate traffic jams and stationary at traffic lights. Following the start up and acceleration simulation, the engine burns better the fuel of the lean mixture (λ>1,05-1,2), but exhausts a nitrogen oxides significant amount due to the increase of speed and temperature in the combustion chamber, resulting the increase of thermal efficiency. On deceleration, the engine speed and combustion temperature decrease occurring the mixture enrichment, which leads to incomplete combustion, power reduction and specific fuel consumption increase. Thus the emitted pollutants during this operation mode consist of large quantities of unburned hydrocarbons and considerable quantities of carbon monoxide.

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