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INVESTIGATIONS ON CAR EMISSIONS UNDER THE URBAN TRAFFIC CONDITIONS WITH THE INFLUENCE ON TIMIŞOARA AIR QUALITY

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Abstract. Poor air quality, a high traffic level and environmental noise as well as traffic congestion and greenhouse gases emissions require establishing measures, necessary to achieve an environmentally-friendly urban habitat. The priority areas of action in order to reduce greenhouse gases emissions are transportation and construction. Implementing sustainable urban transport plans, including specific measures to promote energy-efficient vehicles and to reduce carbon dioxide (CO_2) emissions, will contribute to local reduction of greenhouse gases emissions. In order to evaluate the concentrations of car exhausted emissions under the urban traffic conditions in Timişoara, Romania, which have negative effects on the air quality, experimental researches were achieved regarding the traffic simulation with a non-EURO car operating with two fuel types (petrol and LPG). These researches were performed in the Road Vehicles Lab at the University 'Politehnica' of Timişoara and aimed a route in Timişoara downtown with a large agglomeration of vehicles (a traffic light intersection and a non-traffic light one, 6 pedestrian traffic light crossings and 4 non-traffic light ones). The studied route is of 2.3 kilometers length, where the traffic is carried on 'bar to bar' and is transited in 2588 seconds. As a result of primary pollutants recordings, the values for the engine transition operating mode are obtained which show the necessity of imposing some measures concerning traffic restrictions in agglomerate areas for these car types. The simulation results also revealed that a viable alternative for a short term to reduce the pollutants emissions which has an impact on the urban environment is to use LPG instead of petrol as a fuel for cars as the analyzed one.

Keywords: urban traffic, route, air quality, experimental simulation, Otto engine, exhaust emission, LPG, petrol.

Introduction

One of the most important challenges of the automotive industry is the necessity to reduce fuel consumption and hence carbon dioxide emissions with implications on the environment through the greenhouse effect that causes climate change.

To begin with, almost 40% of carbon dioxide emissions (greenhouse gas) from transport sector are the result of using private cars in the cities. These emissions depend on the engine (Otto, Diesel, etc.) and fuel type (petrol, diesel, LPG, LNG, etc.).

Moreover, exhausted gases of any vehicle contain chemicals (sulfur dioxide, nitrogen dioxide, volatile organic compounds, carbon monoxide, and aromatic hydrocarbons, lead) which have a negative impact on the environment and on human health too.

One more thing worth mentioning is that motor fuels consist of certain types of hydrocarbons of which complete combustion is described by carbon and hydrogen complete combustion equations. Petrol is a mixture of hydrocarbons containing 5 to 10 times and sometimes 12 carbon atoms in the molecule.

The petrol composition consists of (Nenițescu 1985):

- Saturated hydrocarbons with:
  - Linear chain (n-alkenes or paraffin), C_nH_{2n+2};
  - Branched chain (izoalkanes or isoparaffin), C_nH_{2n+2};
  - Cyclic chain (cycloalkanes or naphthenes), C_nH_{2n};
- Mononuclear aromatic hydrocarbons (Arena):
  - Benzene, C_6H_6;
  - Toluene, $C_6H_5–CH_3$;
  - Xylenes, $C_6H_4\ (CH_3)_2$;
- Unsaturated hydrocarbons with one double bond between two carbon atoms (alkenes or olefins), C_nH_{2n};
- Small quantities of organic compounds with S, N, O, etc.

The percentage content of various hydrocarbons in petrol is presented in Table 1 (Nenițescu 1985). The chemical composition of propane Type I and II is presented in Table 2 (Cavaropol 2008).

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Table 1. The percentage content of various hydrocarbons in petrol

Hydrocarbon	Petrol	
	90	98
Paraffins	14÷27	1÷20
Naphtenes	10÷11	1÷4
Aromatics	4÷25	0.8÷4
Olefines	3÷14	1÷3.5

Table 2. The chemical composition of propane, Type I and II

Characteristics	Type I	Type II
Chemical composition, % mass		
• Propane, min	92	93.5
• Hydrocarbons (C_2), total max	5	2.5
• Propylene, max	2	2
• Hydrocarbons (C_4), total max	2	2
Total sulphur, mg/m^{3}N, max	100	
Water, % max	0.05	

1. Global and European Anti-Pollution Legislative Measures

Since 1970, vehicle emissions have been dramatically reduced (Tokar 2009).

By taking into account the vehicles sales estimates, which worldwide are expected to increase in terms of car number, more severe legislative measures are required from anti-pollution rules point of view.

In Fig. 1 the EURO-1÷EURO-6 upper limits allowed by EU regulations are presented (Linke 2009).

An analysis of CO, HC, NO_x and CO_2 emissions global trends depending on the vehicle type shows that cars remain the dominant source of CO and HC.

For this reason, a constant worldwide concern is to reduce these emissions. Given the different operating modes under the urban traffic conditions, a solution to reduce exhausted emissions from vehicles equipped with petrol engine is to use LPG instead. Following its combustion, the engine exhaust gases are much cleaner than the exhaust gases resulted from petrol operation.

Although there are a number of disadvantages of using LPG (loss of strength, wear-piston group segment 50000÷60000 km run), still by taking into consideration the large number of non-EURO registered present vehicles in traffic in Romania the operation with LPG solution is advantageous in terms of emissions.

Average exhaust emission			EU-1 1992	EU-2 1996	EU-3 2000	EU-4 2005	EU-5 2009	EU-5+ 2011	EU-6 2014
Positive Ignition Engines like Gasoline	CO	mg/km	2720	2200	2300	1000	1000	1000	1000
	HC	mg/km			200	100	100	100	100
	HC + NO_x	mg/km	970	500					
	NO_x	mg/km			150	80	60	60	60
	NMHC	mg/km					68	68	68
	PM GDI only	mg/km					5	4.5	4.5
	PN	#/km							?
Compression Ignition Engines like Diesel	CO	mg/km	2720	1000	640	500	500	500	500
	HC + NO_x	mg/km	970	700	560	300	230	230	170
	NO_x	mg/km			500	250	180	180	80
	PM	mg/km	140	80	50	25	5	4.5	4.5
	PN	#/km						6E11	6E11

Moderate Change (<30%) Large Change (>30%)

Fig. 1. EURO-1÷EURO-6 reglementations concerning the pollutant emission limits for light vehicles

Thus, another measure that can be adopted is to restrict the movement of non-EURO vehicles, particularly in central and crowded areas. If this is not possible, the access of such vehicles in these areas should be allowed only if they are equipped with LPG facilities. One of the objectives of Timişoara local authorities is the air quality improvement, thus perfecting an environmentally and friendly urban habitat.

An efficient and flexible transport system is essential for the economy and life quality. Rational solutions that lead to pollution reduction, minimum fuel consumption and an engine long lifetime are: the engine periodical testing and adjusting, avoiding prolonged idling operation at maximum power mode and unnecessary excessive acceleration, compliance with economic speed. At present, the transport system is significantly threatening the human health and the environment.

2. Aspect Regarding the Urban Environment Conditions in Timişoara, Romania

To ensure a comfortable environment appropriate to a sustainable development of Timişoara, a concept can be achieved by optimizing the economic and technological interactions between human society and the environment (Ciupa 2009).

Implementation of rehabilitation, protection and environmental conservation measures will lead to:

- maintaining the urban ecosystem balance;
- the elimination of pollution factors that create discomfort and affect health;
- upgrading the existing potential.

Positive assessments of recent years at the EU level regarding 'Timişoara – City of five stars', reflect the local administration efforts to ensure civilized life conditions, economic and social growth as well as printing of major changes in attitude and civic conduct to more and more people.

In Timişoara, the environment's actual state highlights the community's achievements so far, rated as satisfactory, but also 'weak points' of everyday life. These 'weak points' are determined by:

- investment failure due to lack of budget funds;
- local legislation is not always favorable;
- non-existent ecological attitude due to lack of environmental awareness.

'Weaknesses points' in terms of pollution from transport sector are:

- poor state of roads and the existence of only a city ring portion;
- small area of green zone per inhabitant;
- the continuous aggression on the green areas, due to the need for new urban places and spaces required by the city development;
- chemical pollution, noise, vibration and electromagnetic radiation in Timişoara.

To reduce the impact on the urban environment, the following aspects must be taken into account:

- the pollutant emissions reduction by accepting in traffic vehicles which are in accordance with the pollution rules and ecological fuels;
- the ring roads construction, which is a big problem in Romanian cities;
- the existing transit routes reinforcing (maintenance and repairs) to reduce the traffic congestion on high traffic roads in residential areas.

3. The Test Stand

One of the major causes of air pollution is the vehicles presence in traffic which is not within the pollution rules, meaning especially those vehicles of which emissions are not in acordance with the EURO-1 to EURO-6 regulations. For this reason, investigations were carried out in the laboratory of the University 'Politehnica' of Timişoara, the Road Vehicles Lab, in order to evaluate emissions concentrations resulted from the combustion of two fuel types (petrol and LPG) during transitory operation of a registered in Romania non-EURO car, which travels in Timişoara.

To obtain more precise values for the urban traffic conditions simulation on the experimental stand, meaning as close to real values, the metrological characteristics (class of accuracy, sensitivity, sensitivity threshold, resolution power) and dynamic (dynamic range, transfer function, frequency range) of the used equipment must be regarded. To streamline the developing process of a vehicle, test duration must be reduced.

For achieving the experimental model of the running in traffic conditions simulation (Fig. 2) the LPS3000 roller stand correlated with the AVL Dicom 4000 gas analyzer for pollutants measuring was used (Standard Operating Instructions… 2003; Operating Manual Version… 2001).

LPS3000 allows testing the engine performance. Simulation on Chassis Dynamometer is performed with an eddy-current braking system. LPS3000 can measure both Otto and Diesel engines power.

Fig. 2. Experimental model organization

Air-cooling fan which is connected to the communications console is operated by radio remote control and allows the drag simulation.

During the experimental tests for exhausted emissions sampling it was used the AVL Dicom 4000 gas analyzer which is presented in Fig. 3.

Fig. 3. Dicom 4000 gas analyzer

Infrared measuring is used as CO, HC, CO_2 measurement principle and electrochemical measurement is the principle used for NO_x case (Operating Manual Version… 2001).

4. The Results of the Traffic Conditions Simulation

Under the circumstances of growing number of vehicles trend as a daily necessity, the investigations have aimed to contribute to pollutant emissions evaluation and reduction and to provide a consistent database for future experimental researches.

Experimental investigations were performed in the Road Vehicles Lab from the University 'Politehnica' of Timişoara and, concerning the traffic simulation they have targeted traffic congestion areas both at rush hours and reduced service ones. The studied route (Fig. 4) is 2.3 kilometers length, where the traffic is carried on 'bar to bar'.

The route analyzed on a relatively short distance, creates agglomeration areas with obviously high effects

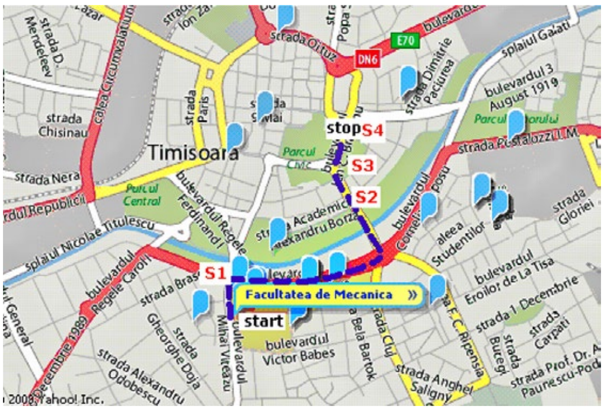

Fig. 4. The analyzed route

on the environment pollution. The route selection has been determined by taking into account the fact that it contains a non-traffic light crossing intersection where five roads can meet. At rush hours in this intersection, often occur traffic jams which lead to idle mode engine operation known as one of the most polluting operating modes. The idle mode duration is of 647 seconds which represents approximately 25% of the total time required to transit the analyzed route. This is a very high percentage for such a short route.

The studied route creates vehicles operating conditions under transitory mode, which involves idling state or slow movement, used to start the engine (cold engine) and for waiting situations (traffic lights, congestion, etc.), acceleration, deceleration, etc.

In order to perform experimental investigations, the BMW 535i E28-non-EURO vehicle operation was controlled. The BMW 535i E28 characteristics are:

- motorization – spark ignition engine (petrol);
- cylinder capacity – 3430 cm^3;
- cylinders number – 6 L;
- maximum power – 160 kW;
- manufacture year – 1986;
- maximum weight – 1390 kg;
- maximum torque – 316 Nm;
- driven kilometers – 380000 km;
- TPI (Technical Periodical Inspections) – 11;
- urban consumption – 16/100km.

The evaluation of simulation possibility on the Chassis Dynamometer of vehicles running in traffic was performed by following the next steps:

- establishing a route that consists of a traffic light intersection and non-traffic light one, 6 pedestrian traffic light crossings and 4 non-traffic light ones;
- the route transit at 2.00 pm that is a rush hour, during which the following parameters were monitored: rotation speed, speed, distances and driving times corresponding to the changes in vehicle speeds;
- the route simulation on the Chassis Dynamometer in the lab by creating climate and operating conditions similar with those recorded during the traffic route transit.

By analyzing the operating time corresponding to each velocity stage during the car transit on the studied road, it can be observed that the gear utilization percentages are:

- for v = 0 km/h, the idling mode is used for 880 seconds which represents a percentage of 34%;
- for v = 8÷17 km/h, the first gear is used for 973 seconds which represents a percentage of 37%;
- for v = 17÷39 km/h, the second gear operating mode is used for 448 seconds which represents a percentage of 17%;
- for v = 33÷49 km/h, the third gear operating mode is used for 220 seconds which represents a percentage of 9%;
- for v = 50 km/h, the fourth gear operating mode is used for 67 seconds which represents a percentage of 3%.

4.1. Comparative Analysis of Exhausted Emissions (Experimental versus Analytical)

In the absence of opportunities for direct measurement of gas composition, exhausted by internal combustion engines, there are methodologies to assess their approximate evaluation. For this purpose, in order to calculate the emissions values the following equations were used (Negrea, Sandu 2000):

The carbon dioxide emission is determined with the following relation:

$$\left|CO_2\right| = \frac{100}{0.329 \cdot L_{\min} \cdot \left(1 + \frac{h}{c}\right) \cdot \lambda + 1}. \quad (1)$$

In accordance with the Romanian standards, the excess air ratio λ for modern engines with spark ignition, with electrical adusting of the mixture formation, λ probe and three-way catalyst is equal to 1 ± 0.03.

According to combustion equations and fuel composition for perfect combustion, the stoichiometric air, L_{min} measured in kg air/kg fuel, to burn one kilogram of fuel, (λ ≥ 1) is:

$$L_{\min} = \left(\frac{1}{0.21}\right) \cdot \left(\left(\frac{8}{3}\right) \cdot c + 8 \cdot h - o + s\right) \quad (2)$$

and for incomplete combustion:

$$L_r = \lambda \cdot L_{\min}, \quad (3)$$

where: h, c, o, s is the content of hydrogen, carbon, oxygen and sulfur from a kilogram of fuel, as percentage in respect of mass and not volume.

If the oxygen content in exhaust gases can not be paramagnetic measured, it will be determined from the relation:

$$\left|O_2\right| = \left(\frac{0.21 \cdot (\lambda - 1) \cdot L_{\min} + o}{L_r + 1}\right) \cdot 100. \quad (4)$$

In case of lean mixtures, CO_2 can be analitically evaluated with an average precision with the relation:

$$\left|CO_2\right| = \frac{100}{0.416 \cdot L_{\min} \cdot \left(1 + \frac{h}{c}\right) - 3 \cdot \left(1 + \frac{h}{c}\right) \cdot \left(1 + \frac{c}{h}\right)}. \quad (5)$$

The carbon monoxide is calculated with the relation:

$$\left|CO\right| = \frac{2897 - 12.01 \cdot L_{\min} \cdot \left(1 + \frac{h}{c}\right) \cdot \left(CO_2 + 0{,}21\right) \cdot \lambda}{12.313 \cdot L_{\min} \cdot \left(1 + \frac{h}{c}\right) \cdot \lambda}. \quad (6)$$

Nitrogen is evaluated with average precision:

$$\left|N_2\right| = 0.329 \cdot L_{\min} \cdot \left|CO_2\right| \cdot \left(1 + \frac{h}{c}\right) \cdot \lambda \quad (7)$$

and hydrogen with good precision as:

$$H_2 = 0.0853 + 0.778 \cdot \left|CO\right| + 0.0869 \cdot \left|CO\right|^2 - 0.0076 \cdot \left|CO\right|^3 + 0.0003 \cdot \left|CO\right|^4. \quad (8)$$

The average precision expressions are derived for calculating the nitrogen oxides and hydrocarbons in general, with the following relation:

$$|NO| = 5.75 \cdot M_K \cdot \frac{|CO_2| + 2\cdot|O_2| - |H_2|}{2.38 \cdot M_L \cdot \left(1+\frac{h}{c}\right) - 5.75 \cdot M_K} + 5.75 \cdot M_K \cdot \frac{\left(6\cdot\frac{h}{c}+1\right)\cdot\left(|CO_2|+|CO|\right)}{2.38 \cdot M_L \cdot \left(1+\frac{h}{c}\right) - 5.75 \cdot M_K} \quad (9)$$

and the total hydrocarbons from exhausted gases:

$$|HC| = 0.396 \cdot \left(2\cdot|CO_2| + |CO| + |H_2O| + 2\cdot|O_2|\right) + 0.396 \cdot 12 \cdot \lambda \cdot L_{min} \cdot M_K \cdot \left(|CO_2|+|CO|\right), \quad (10)$$

where: M_L [kg/kmol] is the air molar mass; M_K [kg/kmol] is the fuel molar mass,

$$|H_2O| = \frac{\rho_{H_2}}{2\cdot\rho_{H_2O}} \cdot |H_2| + \frac{\rho_{O_2}}{16\cdot\rho_{H_2O}} \cdot |O_2|. \quad (11)$$

The Brettschneider equation is (Negrea, Sandu 2000):

$$\lambda = A_1 + A_2, \quad (12)$$

where:

$$A_1 = \frac{|CO_2| + \frac{|CO|}{2} + |O_2|}{\left(1+\frac{H_{cv}}{4}-\frac{O_{cv}}{2}\right)\cdot\left(|CO_2|+|CO|+k_1\cdot|HC|\right)};$$

$$A_2 = \frac{\left(\frac{H_{cv}}{4}\cdot\frac{k}{k\cdot\frac{|CO|}{|CO_2|}} - \frac{O_{cv}}{2}\right)\cdot\left(|CO_2|+|CO|\right)}{\left(1+\frac{H_{cv}}{4}-\frac{O_{cv}}{2}\right)\cdot\left(|CO_2|+|CO|+k_1\cdot|HC|\right)},$$

where: O_{cv} – oxygen/carbon atomic ratio, O_{cv} = 0.0175; H_{cv} – hydrogen/carbon atomic ratio, H_{cv} = 1.7261; k – gase equilibrum constant, k = 3.5; k_1 – conversion factor indicated by the manufacturer.

In order to obtain more precise results, repeated measurements were performed on the test stand for the considered vehicle, while maintaining the same driving conditions (speed, velocity, velocity stage, rolling drag, rolling time, climatic parameters). The obtained values showed very small variations, so that variation curves were approximated by polynomial functions.

The pollutant emissions values obtained from the experimental-calculation comparative studies, for the car running on petrol, are presented in Figs 5÷8 (Tokar 2009).

When the car is equipped with petrol engine it can be noticed (Fig. 5) that CO_2 emission levels have recorded concentration values around 15% during the first 35 minutes of operation, minutes when the car run through all operating modes from idling mode to the full load one, through all velocity stages, from the first gear to the fourth gear, by the pre-established real route simulation. As the thermal engine mode has increased, a CO_2 increasing trend between 25÷30% is observed.

CO variation law (Fig. 6) is positioned below the value of 6% showing slight modulations in time.

High values of NO_x (around 200 ppm) are recorded at acceleration and for higher velocity stages, observing a decrease of these values for lower velocity stages (Fig. 7).

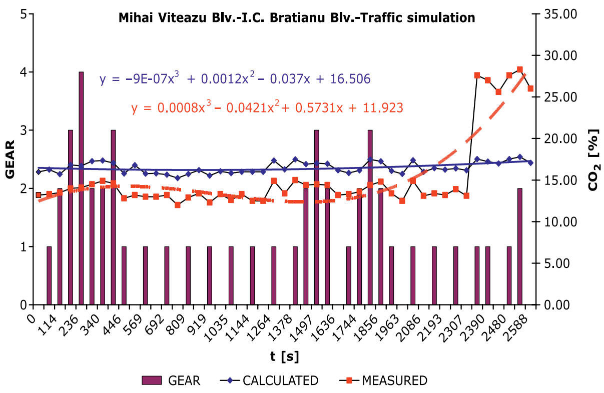

Fig. 5. CO_2 emission versus time for petrol fuel (air conditioning unit is turned off)

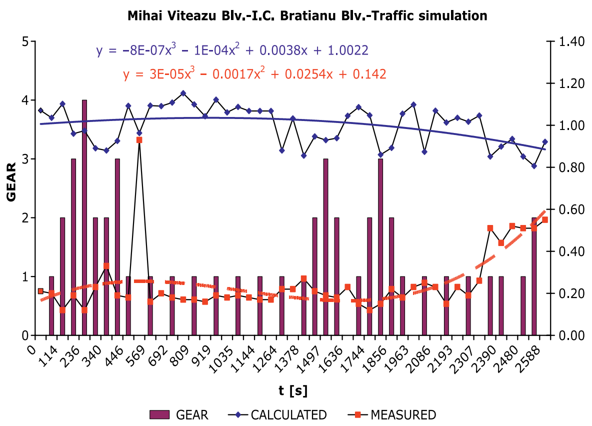

Fig. 6. CO emission versus time for petrol fuel (air conditioning unit is turned off)

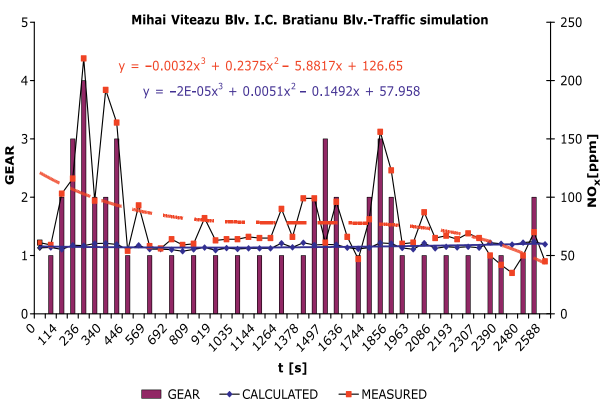

Fig. 7. NO_x emission versus time for petrol fuel (air conditioning unit is turned off)

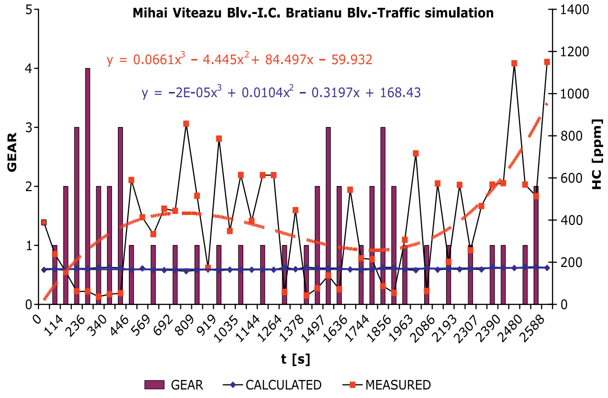

Fig. 8. HC emission versus time for petrol fuel (air conditioning unit is turned off)

HC concentrations have an opposite behavior than NO_x, i.e. high levels up to 1000 ppm are registered at idle mode and lower velocity stages operation (Fig. 8). The calculated values are around 200 ppm.

In the following figures, Figs 9÷12, the comparative results of the exhausted emissions (CO_2, CO, NO_x, HC) for the studied car running on LPG are plotted (Tokar 2009).

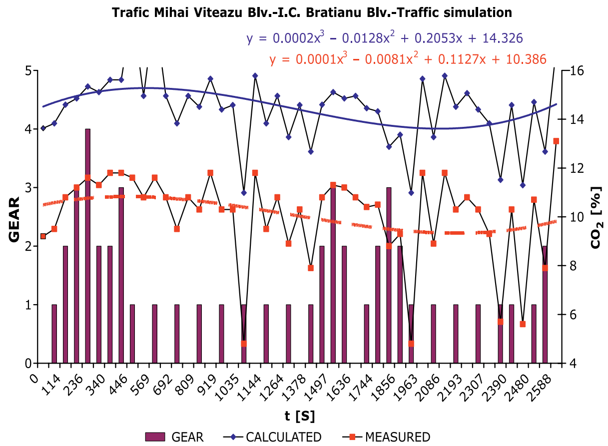

Fig. 9. CO_2 versus time for LPG fuel (air conditioning unit is turned off)

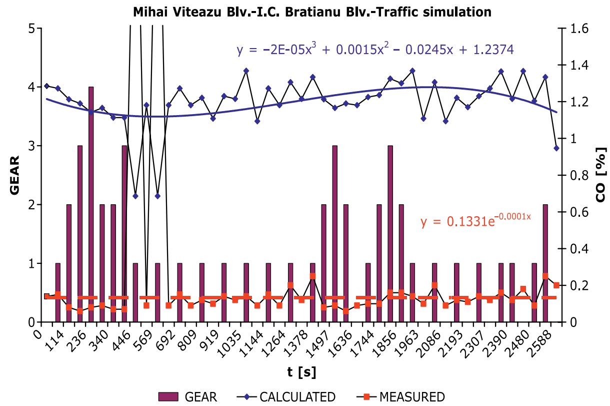

Fig. 10. CO versus time for LPG fuel (air conditioning unit is turned off)

The measured values are above those calculated, being recorded proximities between the measured and calculated values for crossing the first gear of operation.

In the case of CO_2, during an operation with LPG, the allure of the two curves, calculated versus measured, is very similar. The calculated values are within the range of 12÷16% while those measured between 8÷12%. In the case of CO, calculated values are about 6 times lower than those measured.

The calculated values of HC and NO_x emissions are much lower than those measured. Regarding HC emissions values, they are similar only for the first few minutes of operation.

The comparative study results showed that, when operating under variable mode, emissions calculated curves show imperceptible inflections for the same period, while the measured emissions inflection curves are more obvious. This remark leads to the idea that the approximation of measured emissions curves by the resulted polynomial functions can be used to evaluate emissions exhausted by vehicles equipped with similar engines powered with different types of fuels, under the same driving conditions.

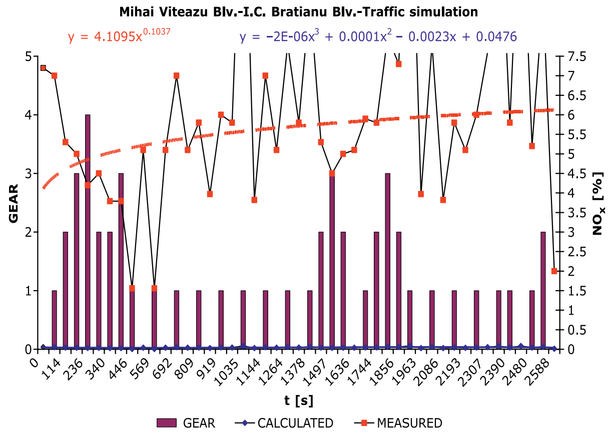

Fig. 11. NO_x versus time for LPG fuel (air conditioning unit is turned off)

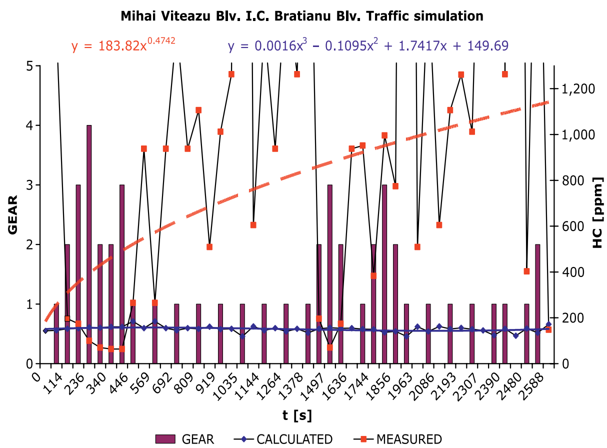

Fig. 12. HC versus time for LPG fuel (air conditioning unit is turned off)

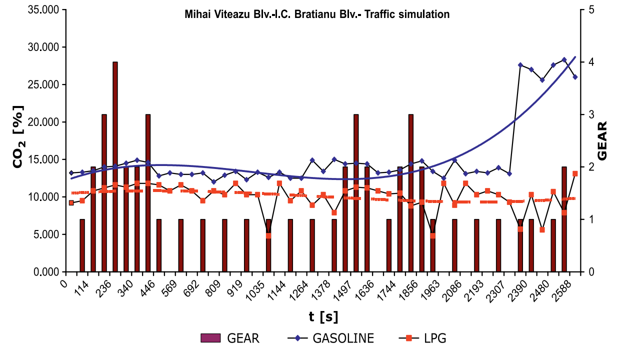

Fig. 13. Compared CO_2 emission versus time (air conditioning unit is turned off) for petrol/LPG fuel

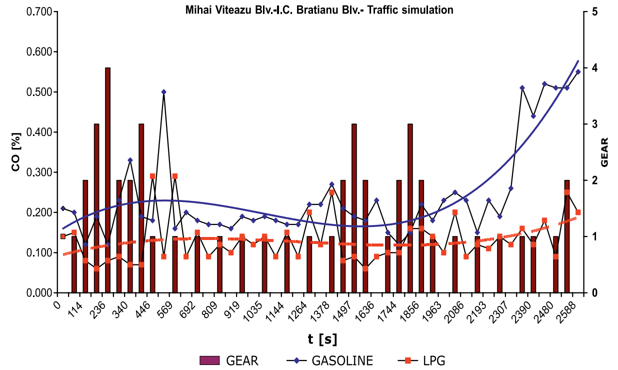

Fig. 14. Compared CO emission versus time (air conditioning unit is turned off) for petrol/LPG fuel

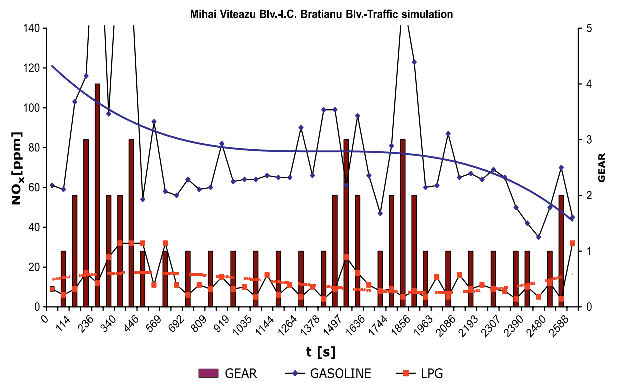

Fig. 15. Compared NO_x emission versus time (air conditioning unit is turned off) for petrol/LPG fuel

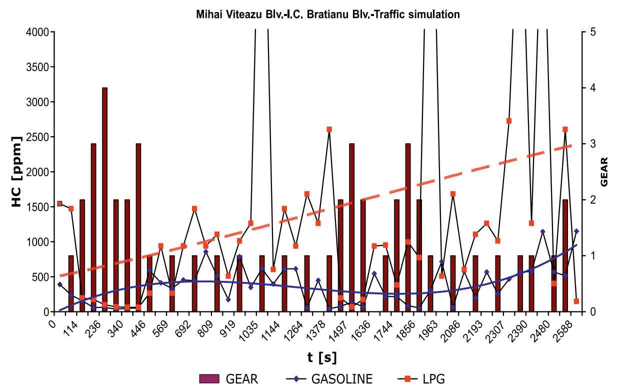

Fig. 16. Compared HC emission versus time (air conditioning unit is turned off) for petrol/LPG fuel

4.2. Comparative Analysis of Exhausted Emissions (Petrol versus LPG)

The comparative diagrams shown in Figs 13÷16 present the emissions exhausted by the non-EURO vehicle running under the urban traffic conditions both on petrol and LPG.

When the vehicle operates on LPG in all operating modes, a 15% to 10% significant decrease in CO_2 concentration can be observed in comparison to the vehicle operating on petrol (Fig. 13). Moreover, by increasing the engine thermal mode, the reduction of CO_2 concentration in exhaust gases is even more relevant, from 30% to 10%.

For the engine operation on LPG, CO emissions have almost a linear trend, falling below 0.2%, being significantly lower than for the engine operating with petrol (Fig. 14).

The average values of NO_x emission concentration are of 15 ppm, showing a slightly decreasing trend along the route and are well above the calculated values (Fig. 15).

While following the default route, the HC emission concentration presents an increasing trend from 150 ppm to over 2000 ppm for the LPG case and is between 500 ppm for the petrol case (Fig. 16). It is noted that the maximum levels are recorded in the route portion with several stops and starts, and at higher speed operation these values are much lower.

Conclusions

1. As results of experimental researches performed on the Chassis Dynamometer in Road Vehicles Lab at the University 'Politehnica' of Timişoara, exhausted emission values for transitory operation mode of the petrol and LPG engines were obtained.
2. Comparing the changes in vehicle emissions during the engine operation under urban traffic conditions, it appears that if the vehicle operates with petrol, CO_2 and CO emissions values are slightly higher in the first minutes of operation than those reported for the LPG case. These emissions sudden become higher as the engine temperature increases.
3. For the engine operating with petrol, NO^x values are 5÷6 times higher compared to the LPG operation. These values are decreasing as the engine operation mode is achieved.
4. Regarding hydrocarbons, the values recorded for the engine operation with petrol are lower than for the LPG case.
5. It results that, moving at a constant speed, the cars equipped with petrol engines eliminate pollutants substances at the lowest levels but it is well known that moving at constant speed it occurs only when routes are long, fluent and without significant restrictions. Urban traffic can provide a constant speed travel only by creating green light routes, which is not easy and does not suit to any urban configuration. Spark ignition engines, at idling, will produce carbon monoxide and unburned hydrocarbons in large quantities.

6. In conclusion, LPG is an alternative for vehicles that are forced to be within the emission standards which are more stringent and for non-EURO vehicles as the studied car case, it becomes a necessity. Modern petrol engines are perfectly suitable for conversion to gas.
7. Given the high emissions exhausted by engines at idle operation due to the traffic congestion, for agglomerate urban intersections it is necessary to restrict traffic in big cities downtown areas at least for non-EURO petrol engines.
8. The conducted researches allow the use of obtained polynomial functions to evaluate emissions exhausted by similar engines fueled with different types of fuels.

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