ANALELE UNIVERSITĂȚII
"EFTIMIE MURGU" REȘIȚA
ANUL XX, NR. 2, 2013, ISSN 1453 - 7397

Arina Negoiţescu, Adriana Tokar

Influence of Urban Traffic Driving Conditions and Vehicle Cubic Capacity on CO and VOC Emissions

The reports regarding the global warming warn on the urgent need to reduce pollutant emissions and in particular greenhouse emissions. The performed analysis shows that cars equipped with engines operating on petrol, lead to a lower level of pollution, from the point of view of CO (carbon monoxide) and VOCs (volatile organic compounds) emissions at speeds above 50km/ h. Since driving in urban traffic mode involves driving with a speed up to 50km/h, it was comparatively analyzed the automobile engines operation with different cubic capacities. In conclusion, in terms of the analyzed emissions in accordance with the emission standards requirements for urban driving situations, it results that the accepted values of these emissions are recorded for automobile engines of low cubic capacities (under 1.4 l).

Keywords*: urban traffic, pollutant emissions, passenger car, cubic capacity*

1. Introduction

In automotive engineering, research and development is focused on vehicle equipped with hybrid or pure electric propulsion system. However, projections for 2020 indicate that only 2.5% of all vehicles sold annually (about 110 million units) are vehicles equipped with pure electric propulsion system [1].

Statistics show that vehicles with internal combustion engines will not be removed, however, their rethinking is necessary. In this respect to reduce emissions and increase efficiency in traffic, it is necessary to adopt technical solutions such as START / STOP or automated driving systems. Although automated driving systems are able to maintain the trajectory on current traffic lane and to perform braking maneuvers in terms of traffic safety, the road infrastructure in Romania is still causing problems. The development of technical systems for reducing emissions is required to fulfill pollution standards imposed by the overall objectives in medium term (2014-2020), Europe 2020. These standards establish a 20% reduction in greenhouse gases emissions or even of 30% under favorable conditions compared to 1990s recordings [2].

2. Aspects regarding greenhouse emissions

In Romania, in order to reduce greenhouse gas emissions from the transport sector there were taken measures such as car fleet renewal in order to upgrade the road transport. According to the National Reform Programme 2011-2013, Annex 1, from March 15, 2013 [2], in 2012 it was reported the registration of 426 hybrid vehicles and 62 electric vehicles.

The EU target for reducing emissions by 20% refers to all emission sources and uses 1990 as a reference year. The evolution of total greenhouse gas emissions from 1990 to 2010 for each country is graphically presented in Figure 1.

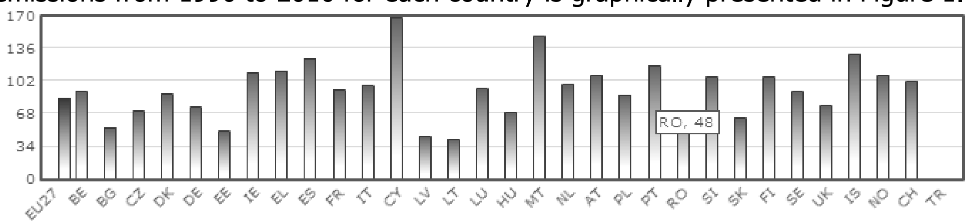

Figure 1. The greenhouse emissions evolution in EU countries [2]

This indicator shows the trends in total greenhouse gases emissions related to 1990 and include: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and so-called F-gases (hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride (SF_6)). The indicator does not include emissions from international aviation and maritime shipping.

These gases are combined in a single unit using indexes of global warming potential (GWP) as characterization factors in order to assess emissions for climate change impact category. This indicator results in kg CO_2 equivalent and is given by relation (1) [3], [4].

$$\text{Climate change} = \Sigma GWP_i \cdot m_i \quad (1)$$

where:

m_i [kg] – the mass of the released substance *i*;

GWP_i - Global Warming Potential of the substance *i*;

The potential contribution to global warming is calculated using a procedure that expresses the substance characteristics in comparison with the ones of other gases. Thus, there has been developed a system of characterization factors capable of weighing various substances depending on their participation as greenhouse emissions. Therefore, it can be estimated the expected contribution to global warming in a selected period of time (20, 100 or 500 years) of a specific substance emission divided to global warming contribution of the emission of an appropriate amount of CO_2. Hence, it can be said that the mathematical definition of the global warming potential index of a substance is determined by the ratio of the absorption of infrared radiation intensified due to the instantaneous emission of 1kg of substance and the one due to an equal emission of CO_2, integrated in time. CO_2 was chosen as a reference substance because it is the substance that has the most significant contribution to the greenhouse effect [4].

For 2013, emissions are estimated at 14% below 1990 levels, dropping to about 21% by 2020 compared to the same reference year. Reported to the base year 2005, the relative reduction of emissions is of 17% and 24% by 2020. The reduction estimation of greenhouse gas emissions in CO_2 equivalent between 2013 and 2020 is presented in Table 1 [5].

Table 1. Greenhouse gas emissions relative reduction between 2013 and 2020

Year	2013	2014	2015	2016	2017	2018	2019	2020
CO_2 equivalent [Mt]	4811	4752	4693	4634	4575	4516	4457	4398
Reduction compared to 1990	-14%	-15%	-16%	-17%	-18%	-19%	-20%	-21%
Reduction compared to 2005	-17%	-18%	-19%	-20%	-21%	-22%	-23%	-24%

The air quality due to emissions from transport is mostly influenced by road traffic congestion. These situations are common in the urban traffic where traffic jams occur frequently.

The emissions values exhausted by automobiles are established by EC regulations. However, during the car real driving, the exhaust pipe emissions can not be directly correlated with emission standards but limitations imposed by these regulations on pollutants are important for traffic management optimization.

3. Calculation methodology for estimation of vehicle emissions

The assessment of emissions from road transport is based on the COPERT III methodology [6].

The main emissions quantities exhausted due to road traffic can be calculated by: category / subcategory of vehicle and emission standards.

The difference between the various driving modes enables the methodology application at full resolution on a street network (e.g. highway) or on an urban area route.

Emission factors vary depending on input data: different operating modes and driving situations, information on fuel consumption, distance traveled, vehicle classes, and climatic conditions.

The engine various operating conditions and, hence, the vehicle emissions concentration are influenced by different driving modes [6].

The characteristic ranges of the average speed for these modes are shown in Table 2.

Table 2. Speed characteristic ranges depending on traffic type

Driving mode	**Speed characteristic ranges [km/h]**
Urban	10-50
Extraurban	40-80
Highway	70-130

Engine emissions at cold start are assigned to driving in urban traffic mode because it is assumed that, in general, vehicles will start in urban parking areas.

The total emission can be calculated with the following equation:

$$E_{total} = E_{URBAN} + E_{EXTRAURBAN} + E_{HIGHWAY} \; [g] \quad (2)$$

where:

E_{URBAN}, $E_{EXRAURBAN}$, $E_{HIGHWAY}$ [g] – the total quantity of pollutant emissions for the three driving modes.

Overall emissions assessments are calculated according to the methodology, based on emission factors given by vehicle manufacturers and on information regarding the operating periods provided by users.

Basically the total emissions are calculated by summing emissions from three different sources, namely:

- Engine running at startup (cold);
- The engine operating under steady thermal conditions (warm);
- The engine operating under overheating conditions when fuel evaporation occurs.

Concentrations of exhausted emissions by automobiles before reaching the engine operation thermal conditions, when exhaust gases treatment systems does not start, depend on a number of factors: driving speed and driving modes, the number of kilometers traveled, the vehicle age, engine type and power.

Taking into account the emission concentration variations depending on the engine thermal conditions during its operation, total emissions can be calculated with the following relation:

$$E_{total} = E_{WARM} + E_{COLD} + E_{EVAPORATION} \; [g] \quad (3)$$

where:

E_{WARM} [g] - Emissions during the steady thermal engine operation (warm);
E_{COLD} [g] - Emissions during the transient thermal engine operation (cold start);
$E_{EVAPORATION}$ [g] - emissions resulted from the fuel evaporation.

Evaporative emissions are relevant only for VOC from spark ignition engines.

The calculation formula for emissions determination of vehicles powered by different fuels is:

$$E_{WARM,i,j,k} = e_{WARM,i,j,k} \cdot N_j \cdot M_{j,k} \; [g] \quad (4)$$

where:

$E_{WARM\ i,\ j,\ k}$ [g]– pollutant *i* emissions exhausted during the engine operation under steady thermal conditions after the start of the flue gas treatment system

(catalysts), during a period of time, for a certain vehicle class *j* and a certain driving mode *k*;
$e_{WARM\ i,\ j,\ k}$ [g/km] - representative average emission factors for the pollutant *i* specific to class *j* of vehicles operating under steady thermal conditions after the start of the flue gas treatment system (catalyst), for a certain driving mode *k*;
N_j [vehicles] - number of *j* class vehicles registered in the reference year;
$M_{j,k}$ [km/vehicle] – mileage of *j* class vehicles for driving mode *k*.

The car speed used for calculation by taking into account the three driving modes has a major influence on vehicles emissions.

Basically, the emissions are calculated for cars and pick-up truck, and emissions factors are available for petrol. A relevant factor corresponding to the ratio between cold gases emissions and warm gases emissions, which is specific to engine start, is used and applied to the distance fraction travelled with cold engine.

Cold emissions are introduced in calculation as additional emissions on each km travelled, with the relation:

$$E_{COLD,i,j} = \beta_{i,j} \cdot N_j \cdot M_{j,k} \cdot e_{WARM,i,j} \cdot \left(e_{COLD,i,j} / e_{WARM,i,j} - 1\right)[\,g\,] \qquad (5)$$

where:
$E_{COLD\ i,j}$ [g] – pollutant *i* emissions at cold start (for the reference year), exhausted by class *j* vehicles;
$\beta_{i,j}$ - the distance fraction travelled with cold engine or before the start of the flue gas treatment system;
$e_{COLD\ i,j}$ / $e_{WARM\ i,j}$ – the ratio between pollutant *i* emission cold gases and warm gases, relevant for class *j* vehicles.

The β parameter depends on the ambient temperature t_A, vehicle type and category and especially on the mileage. According to the available statistic data, the value of the vehicle average annual mileage is established between 8000km and 15000km [8]. In European countries, the average annual mileage was established to 12400km.

The ratio $e_{COLD\ i,j}$ / $e_{WARM\ i,j}$ depends on the ambient temperature and the considered pollutant.

Emissions considered at the start of the engine are specific only for urban mode (S_{URBAN}) as it was taken into account that most of the starts take place in urban areas. A certain fraction of these emissions are also the result of the extraurban driving mode. Therefore, if $\beta_{i,j} > S_{URBAN}$ then equation (5) becomes:

$$E_{COLD,i,j,URBAN} = S_{URBAN,i,j} \cdot N_i \cdot M_i \cdot e_{WARM,i,j,URBAN} \cdot \left(e_{COLD,i,j} / e_{WARM,i,j} - 1\right)[\,g\,] \qquad (5a)$$

$$E_{COLD,i,j,EXTRAURBAN} = \left(\beta_{i,j} - S_{URBAN,i,j}\right) \cdot N_i \cdot M_i \cdot e_{WARM,i,j,URBAN} \cdot \left(e_{COLD,i,j} / e_{WARM,i,j} - 1\right)[\,g\,] \qquad (5b)$$

The emissions assessment depending on various classes and categories cannot be calculated based only some consumption statistics. Therefore, pollutant emissions are being calculated based on the fuel consumption corresponding to vehicle class. Afterwards, a correction is made based on the actual consumption. In mathematical terms this correction can be written with the relation:

$$E_{i,jm}^{CORR} = E_{i,jm}^{CALC} \cdot \frac{FC_m^{STAT}}{\sum_{jm} FC_{jm}^{CALC}} \tag{6}$$

where:

j_m - class *j* (according to COPERT 90 [6]) for the fuel *m*;

$E_{i,jm}^{CORR}$ - The pollutant *i* emission (CO_2, SO_2, Pb, HC) corrected depending on the fuel *m* for the class *j* vehicle;

$E_{i,jm}^{CALC}$ - The pollutant *i* emission, estimated based on the fuel *m* consumption for class *j* vehicle;

FC_m^{STAT} - The total (actual) fuel consumption (leaded petrol, unleaded petrol, diesel, LPG) based on the calculated fuel consumption for the class *j* vehicle;

$\sum_{jm} FC_{jm}^{CALC}$ - The total fuel consumption calculated for all classes *j* vehicles operating with fuel *m*.

In this regard, the emissions total assessments for any pollutant are equal to the ones obtained based on statistical calculations of the fuel consumption and emissions information for different vehicle classes.

The CO_2 final emissions are estimated based on the fuel consumption assuming that the fuel carbon content is completely oxidized and is determined with the equation:

$$E_{CO_2,j}^{CALC} = 44,011 \cdot \frac{FC_{jm}^{CALC}}{12,011 + 1,008 \cdot r_{H:C,m}} \tag{7}$$

where:

$r_{H:C,\,m}$ – the ratio between the fuel hydrogen and carbon atoms (~ 1,8 for petrol).

When the total emissions are being calculated, besides the CO_2 final emissions there are also calculated the other emissions which content carbon atoms such as, CO, VOC and particle emissions. Thus, in order to calculate the CO_2 final emissions, the following equation is applied:

$$E_{CO_2,j}^{CALC} = 44,011 \cdot \frac{FC_{jm}^{CALC}}{12,011 + 1,008 \cdot r_{H:C,m}} - \frac{E_{jm}^{CO}}{28,011} - \frac{E_{jm}^{VOC}}{13,85} - \frac{E_{jm}^{PM}}{12,011} \tag{8}$$

4. The assessed analysis of the CO an VOC emissions exhausted by vehicles equipped with petrol engines, driving in urban traffic

In order to asses the emissions from the road transport it was used the Road Transport Emission Factors' Calculator software [7] based on the COPERT III methodology [6].

The case study contains the assessed calculation of CO and VOC emissions exhausted by car engines with various cubic capacities. These cars were considered driving in urban traffic. The analysis was performed for the speed range between 10km/h and 50km/h, for various car categories equipped with petrol engines.

4.1. Variations of CO and COV emissions from cars driving under urban traffic conditions

For cars equipped with various cubic capacity petrol engines corresponding to EURO 5 emissions standards, there were approximate calculated the CO and VOC emissions from urban road transport with Road Transport Emission Factors' Calculator software [8].

The CO and VOC emissions quantity was assessed depending on the driving speed for various categories and subcategories of vehicles.

In Figure 2 is presented the fuel consumption variation for the passenger cars, depending on the each type of car cubic capacity.

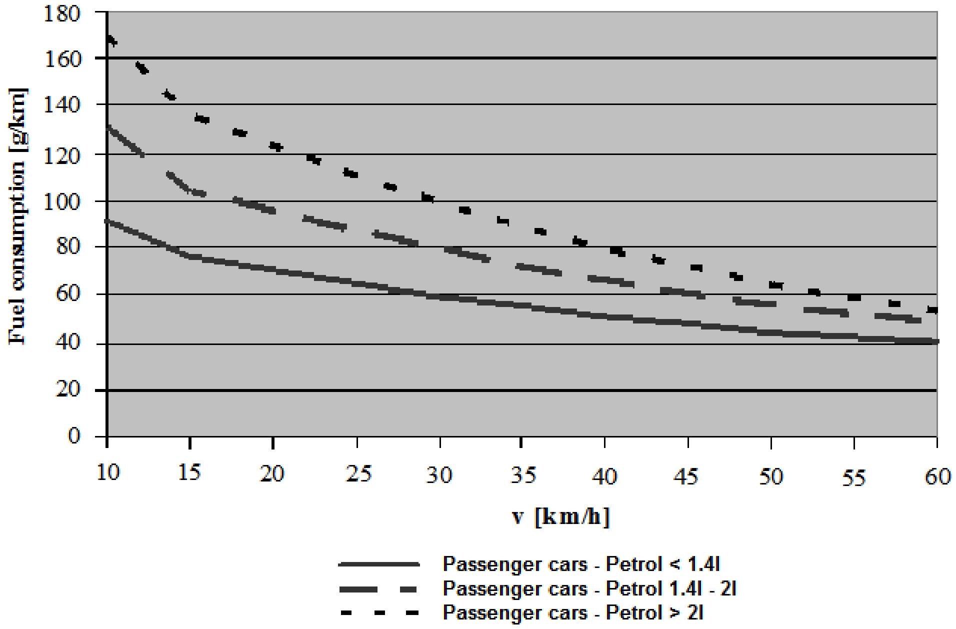

Figure 2. The fuel consumption variation

From the graphic analysis there can be observed significant differences regarding the fuel consumption between the engine start conditions and the unstable operating engine conditions in comparison with the steady operating mode. For the first two operating modes the differences are from 40g/km to 80g/km, for the last engine operating mode the recorded differences are less than 20g/km, corresponding to the three passenger cars subcategories.

In Figure 3 is presented the CO emission variations for the three considered passenger cars subcategories.

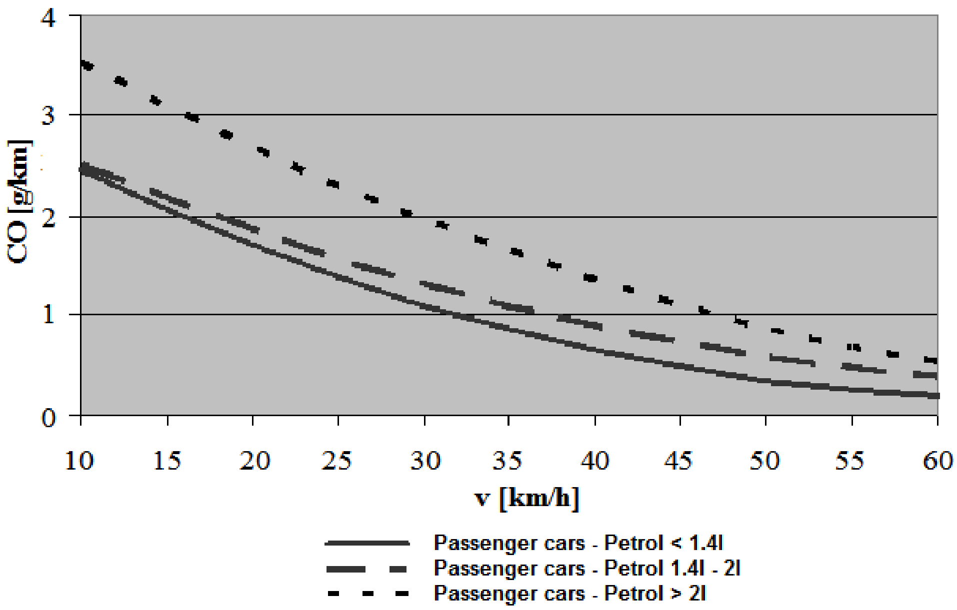

Figure 3. CO emissions variation

From CO emissions point of view, it can be observed that the cars with cubic capacities smaller than 2l exhaust in urban traffic mode emissions having comparable values for the two car subcategories. For the passenger cars with cubic capacity higher than 2l the emission values are at least with 1g/km higher during the overall engine operation period.

As it was to be expected, from the performed analysis it can be concluded that passenger cars equipped with engines having cubic capacity under 1.4l bring the smallest contribution to the carbon quantity exhausted into the atmosphere

The VOC emissions variations values, presented in Figure 4 for the three considered passenger car subcategories, reinforce the previous conclusions but recommend the cars with cubic capacity engines between 1.4l and 2l for urban traffic mode.

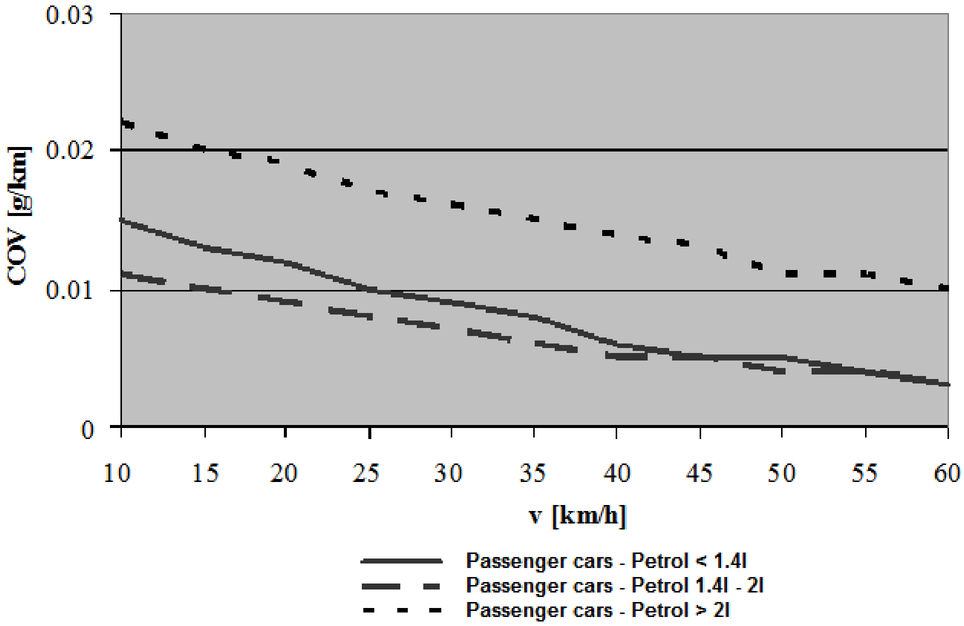

Figure 4. VOC emissions variation

4.2. Determination of the CO total quantity exhausted into the atmosphere by a EURO 5 passenger car driving on an urban route

The analysis of the CO total emissions exhausted by three subcategories of passenger cars with engines operating on petrol was performed for highlighting the influence of the cubic capacity on pollutant emissions.

For this purpose it was simulated an urban route that includes crowded areas. It was assumed that the three categories of passenger cars were driving on the same route under the same conditions.

The considered route ensure the car engines to operate under transient mode which means both driving at idle which is used for starting the engine (cold engine) and waiting situations (traffic lights, traffic jams, etc.), acceleration, deceleration, etc., [9].

The simulated route has a total length of 15km ant it is driven in time interval of 30 minutes. The distances, time, CO quantities of the analyzed cars are presented in Table 3.

Table 3. Assessment of the CO total quantity, exhausted by EURO 5 petrol cars

Passenger cars - Petrol -EURO 5										
Speed [km/h]	10	15	20	25	30	35	40	45	50	55
Distance [km]	1.5	0.2	1.5	0.5	1.2	1	1.3	2.8	4.5	0.5
Time [min]	9.00	0.80	4.50	1.20	2.40	1.71	1.95	3.73	5.40	0.55
Passenger cars - Petrol <1.4l										
CO [g/km]	2.45	2.05	1.67	1.38	1.09	0.85	0.65	0.48	0.34	0.25
CO total [g]	3.67	0.41	2.55	0.69	1.32	0.85	0.84	1.33	1.55	0.12
CO total quantity exhausted on the whole route: 13,33g										
Passenger cars - Petrol 1.4l<2l-										
CO [g/km]	2.50	2.15	1.84	1.56	1.30	1.07	0.88	0.71	0.57	0.47
CO total [g]	3.74	0.43	2.76	0.78	1.56	1.07	1.14	1.99	2.58	0.23
CO total quantity exhausted on the whole route: 16,29g										
Passenger cars - Petrol >2l										
CO [g/km]	3.52	3.08	2.67	2.29	1.94	1.63	1.34	1.09	0.87	0.68
CO total [g]	5.28	0.62	4.00	1.15	2.33	1.63	1.75	3.05	3.90	0.34
CO total quantity exhausted on the whole route: 24,03g										

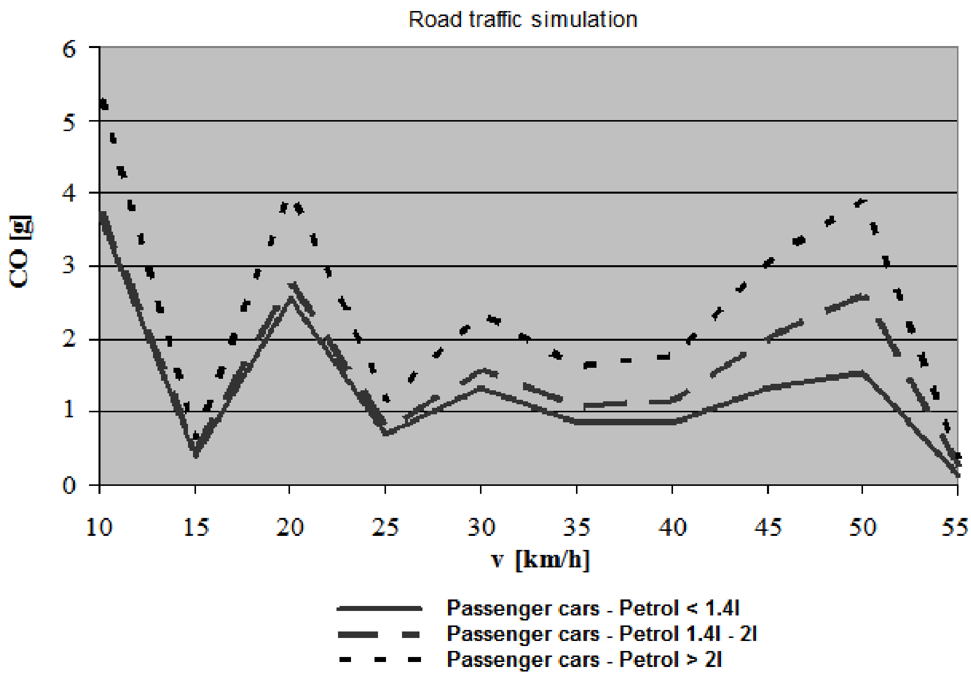

Figure 5. CO emission variations for the simulated route

For all three EURO 5 car categories (cubic capacity: under 1.4l, between 1.4 and 2l and over 2l) operating with petrol there were plotted the assessed CO total emissions, which are shown in Figure 5.

By analyzing the CO emission total amount for the simulated route it can be observed that passenger cars with small cubic capacity are preferable for driving in urban traffic, at car speed lower than 50km/h. Running at speeds relatively constant, within 35-50km/h, significantly reduces the total amount of carbon emitted into the atmosphere. High CO emission concentrations are recorded at engine startup and for speed range between 10-30km/h, which is specific to cars running in traffic jams when repeated accelerations and decelerations occur. The idle mode is the most pollutant mode, thus the amount of CO emissions is the highest.

5. Conclusions

From the performed analysis it can be observed that passenger cars equipped with EURO 5 petrol engines ensure a lower pollution level regarding CO and VOC emissions at speeds higher than 50km/h. Under the circumstances that the driving mode in urban traffic assumes running at speed of maximum 50km/h, were comparatively analyzed cars with various cubic capacity engines, driving under the conditions imposed by this driving mode.

In conclusion, in terms of emissions considered in accordance with the requirements of emission standards for urban driving situations, it can be said that the accepted values of these emissions are recorded for cars with small engine cubic capacity (under 1.4l).

If greenhouse gas emissions reduction is not achieved by 30% until 2030 and 60-80% until 2050 in comparison with the base year, i.e. 1990, the consequences on climate impacts could be irreversible.

Considering the pollutant effect of motor vehicles in urban areas, with all the sustained effort to improve their operational conditions is necessary to apply radical measures aimed at reconsidering anti-pollution technologies.

References

[1] Oloeriu F., *Soluţii noi de la compania Bosch GmbH, Autovehiculele pur electrice, incerte în viitorul apropiat*, Info SIAR, Buletin editat de Societatea Inginerilor de Automobile din România, Nr. 103, iulie 2013.

[2] ***** , *Europe 2020 targets, State of play in Romania, Greenhouse gas emissions*, 2013, http://ec.europa.eu/europe2020.

[3] UNEP, *Evaluation of Environmental Impacts În Life Cycle Assessment*, Paris, 2003, p. 108.

[4] Heijungs R.J., et all, *Environmental Life Cycle Assessment of products. Guide and Backgrounds. CML*, Leiden University, Leiden, 1992.

[5] ***** , *Danish Presidency of the Council of the European Union, Submission by Denmark and the European commission on behalf of the European union and its member states*, Copenhagen, 19 April 2012, http://unfccc.int.

[6] ***** *Road Transport Emission Factors' Calculator*, http://www.fi.lt/afch,

[7] Ntziachristos L., Samaras Z., *Computer program to calculate emissions from road transport*, Methodology and emission factors COPERT III, (Version 2.1).

[8] André M., Hammarström U., Reynaud I., *Driving statistics for the assessment of air pollutant emissions from road transport*, INRETS report, LEN9730, Bron, France, 1998, p.186.

[9] Negoiţescu A., Tokar A., *Investigations on car emissions under the urban traffic conditions with the influence on Timişoara air quality*, Transport, Volume 28, Issue 1, Taylor&Fancis, 2003, p. 38-45.

[10] Tokar A., Negoiţescu A., *Comparative Analysis of Exhausted Gases Opacity under Urban Traffic Conditions*, 8th IASME/WSEAS International Conference on Heat Transfer, Thermal Engineering an Environment (HTE'10), Taipei, Taiwan, 20-22nd August, 2010, p. 209-213.

[11] Tokar A., Negoiţescu A., *Variation of CO_2, HC, NOX Emissions for an EURO III Engine under Urban Traffic Conditions*, WSEAS Transaction on Heat and Mass Transfer, Vol. 7/2, April, 2012, p. 37-46.

Addresses:

- Lect. Dr. Eng. Arina Negoiţescu, Faculty of Mechanics, University ”Politehnica” Timişoara, 1 Mihai Viteazu Blv., 300222 Timişoara, arina.negoitescu@yahoo.com
- Lect. Dr. Eng. Adriana Tokar, Faculty of Civil Engineering, University ”Politehnica” Timişoara, 2 Traian Lalescu Street, 300223 Timişoara, adriana_tokar@yahoo.co