

Variability in Vehicle' Exhaust Emissions and Fuel Consumption in Urban Driving Pattern

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Abstract Over the past several decades, Egypt observed rapid expansion of the transportation sector and increased fuel consumption triggered by rapid growth in population and urban areas. This has led to massive increase in number of vehicles and private vehicle per capita. In this paper, data for statistical analysis have been collected, where the remote sensing measurements based on one international cycle for urban area in Cairo, Egypt. Investigation of exhaust emission pollutants emitted by gasoline vehicles in metropolitan area of Cairo, Egypt has revealed four major pollutants affecting the emission rates of nitrogen oxide (NO_x), carbon monoxide (CO), carbon dioxide (CO₂) and hydrocarbon (HC). The variables affecting these pollutants are vehicle age, fuel delivery system, fuel composition and availability of catalytic converter. Moreover, Fuel consumption of three in-use passenger vehicles under laboratory driving conditions is estimated using the emission pollutants derived from remote sensing and the fuel consumption formulation. The results indicate that the estimate of fuel consumption due to NO_x emission pollutant ranged between 0.116-4.139 kg/km, due to CO emission pollutant ranged between 2.288-8.964 kg/km and due to HC emission pollutant ranged between 2.440-10.893 kg/km.

Keywords: urban driving, in-use private vehicles, standard driving cycles, emission pollutants, fuel consumption, vehicle age, fuel delivery system, remote sensing

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1. Introduction

The continuous sampling, which was capable of reflecting real time variation of gas levels, with a margin of uncertainty related to the response time of the sensor and to the speed of concentration fluctuation. Grab sampling allowed the determination of average gas concentration over the whole sampling period eliminating thus the uncertainties associated with the continuous method. As studies of in-vehicle carbon monoxide (CO) exposure often show rapidly fluctuating CO levels and were increasingly using the continuous electrochemical sensing method, the present activity aimed at validating the suitability of the latter method for this monitoring task. For this purpose, an electrochemical CO sensing monitor was used to continuously monitor CO level inside and outside of a vehicle moving in an urban area, and to analyze the content of concomitantly taken grab samples. Trip-average CO levels were measured using the two testing methods and were compared. For CO levels were higher than the instrument detection limit (1 ppm), the observed percent difference between continuous and grab sampling results varied within a fairly acceptable range (0.6–15.4%). The regression of continuous sampling data against grab sampling data revealed an average error of 6.9%, indicating the suitability of the continuous electrochemical method for monitoring in-vehicle and

exterior average CO concentration under typical urban traffic conditions [1,2].

Statistical path model for the gasoline vehicular emissions carbon monoxide (CO), carbon dioxide (CO₂) and hydrocarbon (HC) and contributing to emission tests failure in urban area has been established. 240 gasoline-fueled vehicles have been tested. Diesel vehicles have been excluded because the emissions testing equipment was not available. Different vehicle characteristics have been assessed including vehicle age, country of origin, fuel type, engine size, fuel delivery system, daily driving distance, and inspection and maintenance period. Based on our observation, the German and the Japanese cars were associated with increasing vehicle emissions and were the most likely to fail the Jordanian emission tests. Results also showed that vehicle age, fuel delivery system, fuel composition and availability of catalytic converter were the major factors affecting the emission rates of CO, CO₂ and HC and contributing to emission tests failure. Maintenance program was strongly correlated with CO₂ and HC but was poorly correlated with CO concentrations. Engine size showed no statistically significant relationship with vehicular emissions [3,4,5].

The exhaust emissions and fuel consumption rate of newly registered automobiles were assessed from the European standard driving cycle. The European driving cycle showed the characteristics of vehicles operating conditions for various speeds and acceleration ranges, but did not represent realistic speed-time history of a vehicle

in actual traffic. As the driving conditions were different, the assessment results using this driving cycle may not produce realistic amounts of emissions and fuel consumption of the cars under any traffic which was well known for its congestion. Proposed method to develop a driving cycle to represent city traffic is outlined. The method for selecting the representative road routes was firstly proposed. Gasoline passenger cars equipped with a real time data logger were then used to collect speed-time data under actual traffic along the selected road routes in urban area for two months. The driving characteristics were analyzed from the speed-time data and its target driving parameters were defined and evaluated. The method for generating the driving cycle was then proposed and described. After achieving a driving cycle, exhaust emissions and fuel consumption of vehicles were measured by driving a car on a standard chassis dynamometer according to the obtained driving cycle. Comparison of the exhaust emission test and fuel consumption test results obtained from the constructed driving cycle with those obtained from the presently-adopted European standard cycle had been made [6,7,8,9].

The fuels such as CNG, HCNG, LPG, LNG, Bio-Diesel, Biogas, Hydrogen, Ethanol, Methanol, Di-Methyl Ether, Producer gas, P-series have been tried worldwide. Hydrogen as a future fuel for IC engines was also being considered. But several obstacles had to overcome before commercialization of Hydrogen as an IC engine fuel for automotive sector. Hydrogen and CNG blends (HCNG) might be considered as an automotive fuel without any major modification in the existing CNG engine and infrastructure. A strategy has been worked out for converting the optimized CNG engine to run on HCNG. The testing was carried out for the neat CNG and 5% blends of Hydrogen by volume with CNG. It was observed in the experimental work that the HCNG engines were more superior to CNG engines from fuel economy, power output and emission compliance point of view. The power improvement of 3 to 4%, torque improvement of 3% and fuel consumption reduction of 4% is observed in HCNG engine than the neat CNG engine. The HCNG engine increases the H/C ratio of the fuel, which drastically reduced the carbon based emissions such as CO, CO₂ and HC. To increase the flame speed of HCNG engines, the ignition timing needs to be retarded; this results in reduction of NO_x emissions. The HCNG reduced CO emissions by 40 to 50%, NMHC emissions by 45% and NO_x emissions by 20 to 30% than the neat CNG operation. It showed that the blended HCNG fuel was more environmental friendly. It was important to note that 5% blends of hydrogen by volume with CNG the phenomenon of hydrogen embrittlement did not occur with respect to engine components, hence no major change was anticipated in fuel system and engine components [10,11].

The potentials of using compressed natural gas (CNG) as the main fuel instead of gasoline in a 1.5 liter, 4-cylinder, retrofitted spark ignition car engine at different loading conditions. The engine was converted to computer integrated bi-fueling system from a gasoline engine, and operated separately either with gasoline or CNG using an electronically controlled solenoid actuated valve system. A personal computer (PC) based data acquisition and control system was used for controlling all the operation. A detailed comparative analysis of the engine

performance and exhaust emissions using gasoline and CNG has been made. It is observed that the CNG shows low power, low brake specific fuel consumptions, higher efficiency and lower emissions of CO, CO₂, HC but more NO_x compared to gasoline [12,13].

The alternative fuels which were of great interest since they can be refined from renewable feed stocks, and their emission levels can be lower than those of conventional fueled engines. Despite the fact that alternative fuels were not currently widely used in vehicular applications, using these kinds of fuels was definitely inevitable in the future. In this study, a computer code was developed in Matlab environment and then its results were validated with experimental data. This simulated engine model could be used as an appropriate mean to investigate the performance and emission of a given SI engine fueled by alternative fuels including hydrogen, propane, methane, ethanol and methanol. Also, the superior of alternative fuels was shown by comparing the performance and emissions of alternative fueled engines to those in conventional fueled engines [14,15].

Forty-nine light-duty gasoline vehicles were tested. The driving parameters and vehicle emissions were recorded second by second, on the basis of which the vehicle emission characteristics in Chinese cities were analyzed. There were significant differences for VSP mode distributions on different kinds of roads. On freeways, the emissions and fuel consumption were relatively low. The emission factors and fuel consumption rates on arterial roads and residential roads were approximately 1.4–2 times those on freeways. Therefore, it was necessary to improve the traffic situation to alleviate the emissions in cities. There was no doubt that the new vehicle emission standards implemented recently have made great improvements on lowering the emission level per vehicle. The Euro II vehicle standard has resulted in much lower emission rates. According to our study, there was a reduction of 86.2, 88.2, and 64.5% in CO, HC, and NO_x emission factors, respectively, for Euro II vehicles, compared with carburetor vehicles. However, although the emission levels of individual vehicles were decreasing, where the total amount of vehicle emissions were probably increasing because of the continuing rapid increase in the vehicle population of Chinese cities and other factors. More comprehensive factors to reduce the total amount of emission from vehicles need to be examined [16].

In this paper, data for statistical analysis have been collected, where the remote sensing measurements based on one international cycle of Japanese driving cycles (15-mode) for urban area. The laboratory chassis dynamometer is considered as base of measurements. Moreover, the time history of the fuel consumption of two in-use passenger vehicles under laboratory driving conditions is estimated.

2. Vehicle Fuel Consumption Estimation

2.1. Background

Roadside remote sensing has been used as an effective tool to evaluate real-world vehicles emission characteristics. Remote sensing can accumulate a large number of

samples under real-world driving conditions in a relatively short time at low cost. Mass based vehicle emission pollutants, which are more informative than concentration factors have been derived from the volume-based concentration measured by remote sensing.

2.2. Methods for Calculating

The conversion from volume concentration of CO, HC, and NO to their fuel-specific mass emission pollutants E_{CO} , E_{HC} , and E_{NO} may be expressed as follows [17].

$$E(t)_{CO}(gl^{-1}) = 1200 \frac{Q(t)}{1 + Q(t) + 3Q'(t) / 0.493} \quad (1)$$

$$E(t)_{HC}(gl^{-1}) = 1800 \frac{Q'(t) / 0.493}{1 + Q(t) + 3Q'(t) / 0.493} \quad (2)$$

$$E(t)_{NO}(gl^{-1}) = 1293 \frac{Q''(t)}{1 + Q(t) + 3Q'(t) / 0.493} \quad (3)$$

Where the Q , Q' and Q'' are the ratio of CO, HC, and NO to CO_2 from remote sensing measurement. The emission factor of NO_x expressed as NO_2 is more widely used in emission regulations, and thus emission inventory. A scaling factor of 1.5332 was applied to the above equation for E_{NO} to convert the mass emission factor of NO into NO_2 .

Table 1. Binning in MOVES [19]

• Idle (bin 1)				
Vehicle Speed (km/h)				
No.	VSP (kW/t)	0-40	40-80	>80
1	<0	Bin 11	Bin 21	
2	0-3	Bin 12	Bin 22	
3	3-6	Bin 13	Bin 23	
4	6-9	Bin 14	Bin 24	
5	9-12	Bin 15	Bin 25	
6	>12	Bin 16	Bin 26	Bin 36
7	6-12			Bin 35
8	<12			Bin 33

Both vehicle speed and engine load have been widely used as the two primary dependent variables for transient fuel consumption modeling. To better account for the effect of real-world driving conditions, in-use vehicles measurement results have been modeled with both vehicle speed and engine load to derive transient fuel consumption for the emissions pollutants calculation. Vehicle specific power (VSP) was first derived as an alternative to engine load for analyzing the vehicle emission remote sensing result [18]. In the recent multi-scale emission model (MOVES) [19], the fuel consumption can be modeled based on vehicle speed and VSP. Table 1 lists all of the

bins that have been used in MOVES to model fuel consumption.

The same binning method has been applied in this work. Because all of the remote sensing records were collected in an urban area with moderate speed limits, all of the bins with vehicle speeds over 80 km/hr and Bin1 (Idle) were not included in this work. The fuel consumption binning results based on real world testing can be predicted. Since fuel economy is roughly proportional to vehicle weight. The modeled transient fuel consumption should be scaled according to individual vehicle weight as follows.

$$FC_j = FC_p x \frac{W_j}{W_p} \quad (4)$$

FC_j is the modeled fuel consumption of remote sensing record j . FC_p is the binned fuel consumption modeled with the binning method of the corresponding technology group. W_j and W_p are the effective weight of the recorded vehicle and binned vehicle, respectively, which are calculated by adding 150 kg to the vehicle curb weight.

The distance-based mass emission pollutants EF_i under real-world driving conditions were derived by combining the fuel-based mass emission pollutants E_i and modeled transient fuel consumption FC_j . The conversion process for gaseous pollutant i can be expressed as follows, where v is the vehicle speed of the specific remote sensing record [20]:

$$EF(t)_i(gkm^{-1}) = E(t)_i FC_j / V(t) \quad (5)$$

The total distance-based mass emission pollutants for one vehicle at specific speed (TFC_j)

$$TFC_j(gkm^{-1}) = \sum_{i=1}^{i=n} EF(t)_i(gkm^{-1}) \quad (6)$$

The same method was applied to all the valid remote sensing records collected and the distance-specific emission pollutants derived were used for further statistical analysis.

3. Experimental Methodology

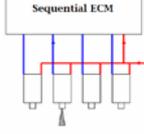
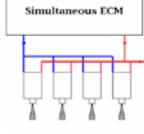
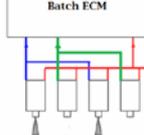
3.1. Vehicles Used in the Present Work

Three vehicles with significantly different fuel injection systems, accumulated mileages, curb weight, model and power. Table 2 tabulates information of vehicles used in fuel consumption predictions. The vehicles are denoted Vehicle 1 through 3. All the vehicles are equipped by with catalyzer, while the weight of the vehicle is equal to curb weight plus weight of two passengers (150 kg). Table 3 shows the fuel injection system used in each vehicle.

Table 2. Information of vehicles used in fuel consumption predictions

Vehiclenu number	Displacement, L	Accumulated Mileage, km	Curb weight		Model year	Power, kW @ rpm	kW/t
			kg	tone			
1	1.6	95655	1230	1.230	2006	78.68 @5800	63.96
2	1.6	150567	1140	1.140	2005	97.06@6000	85.14
3	1.6	78467	1120	1.120	2003	77.06@6000	68.80

Table 3. The fuel injection system used in each vehicle

Vehicle number	Vehicle	Injection System MPI	Fuel	Remarks
1			Gasoline	
2			Gasoline	
3			Gasoline	

3.2. The Japanese Driving Cycle

The Japanese driving cycles belong to the modal cycles. The 10-15 mode Cycle is currently used in Japan for emission certification and fuel economy for light duty vehicles. It is derived from the 10 mode cycle by adding another 15-mode segment of a maximum speed of 70 km/h. Emissions are expressed in g/km [Japanese Industrial Safety and Health Association, JISHA 899, 1983]. The entire cycle includes a sequence of a 15 minute

warm-up at 60 km/h, idle test, 5 minute warm-up at 60 km/h, and one 15-mode segment, followed by three repetitions of 10-mode segments and one 15-mode segment. Emissions are measured over the last four segments (3×10-mode + 1×15-mode). The distance of the cycle is 4.16 km, average speed 22.7 km/h, duration 660 s (or 6.34 km, 25.6 km/h, 892 s, respectively, including the initial 15 mode segment). In this work, the Japanese driving cycle in its 15-mode is used in this work to represents urban driving, and it is shown in Figure 1.

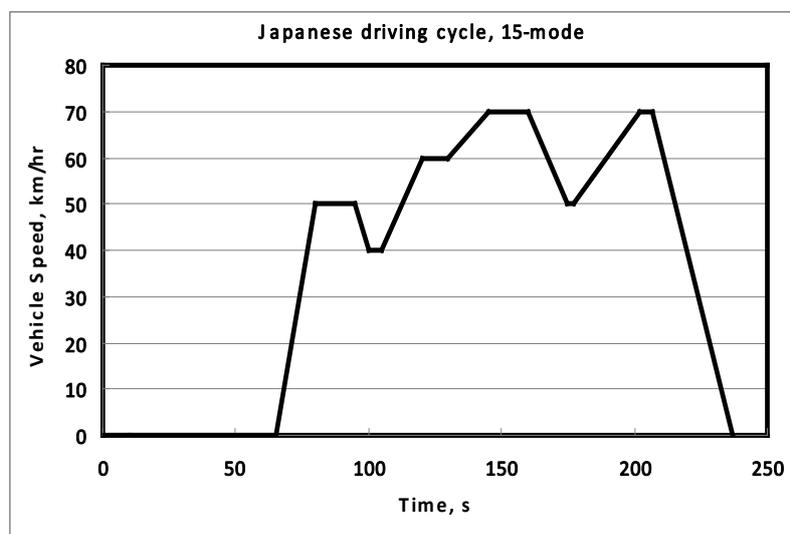


Figure 1. Japanese driving cycle, (15-mode)

3.3. Test Procedure.

The experimental work is carried out on three passenger vehicles considered, were tested on a laboratory chassis dynamometer. The vehicle is equipped with infrared gas analyzer. The exhaust gas concentration, vehicle speed and time are recorded during the test. The gas analyzer and its accessories are mounted in the rear seat of the passenger cabinet. Rechargeable power supply laptop is the most important attachment to the analyzer. Gas sampling probe with 3 m long inserted inside the muffler. Its other terminal is connected to the gas analyzer through the window of the rear door.

During the test, three persons are required to carry out the experimental work. The first is the vehicle driver, which perform the test program with certain sequence .the second person to start gas analyzer record during test. The third person was to help the driver to follow the driving cycle. Test cycle was performed on a laboratory chassis dynamometer. The test methods and conditions were standardized, where overviews of the test procedure are shown in Figure 2, Figure 3 and Figure 4. The time history of the transient tests and comprises measuring nitrogen oxide (NO_x) hydrocarbon (CO), carbon dioxide (CO₂), total hydrocarbon (THC) based on Japanese driving cycle (15-mode) for urban driving.

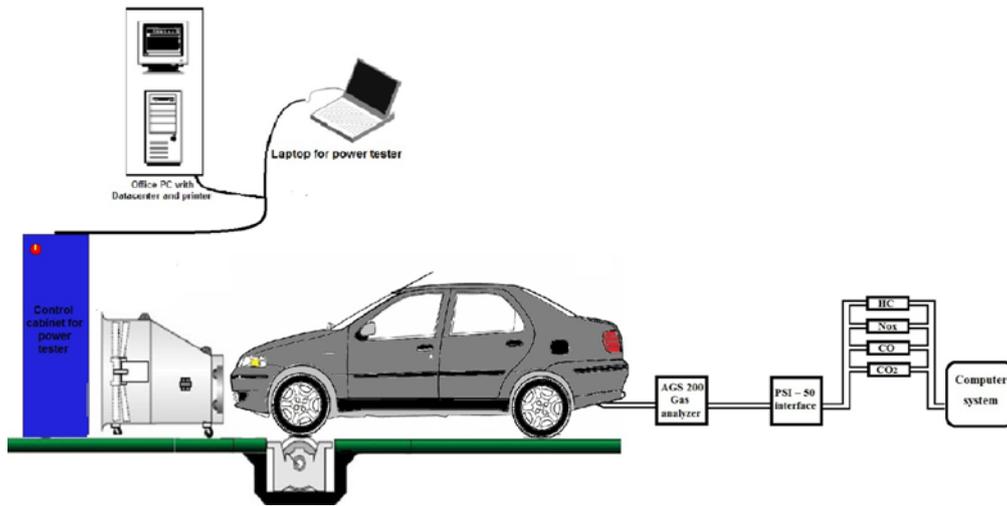


Figure 2. Overview of the laboratory chassis dynamometer test



Figure 3. Overview of the vehicle on chassis dynamometer roller



Figure 4. Overview of the vehicle with the measuring equipment

except for NO_x (Figure 5) profile which is a relatively consistent with the driving cycle profile.

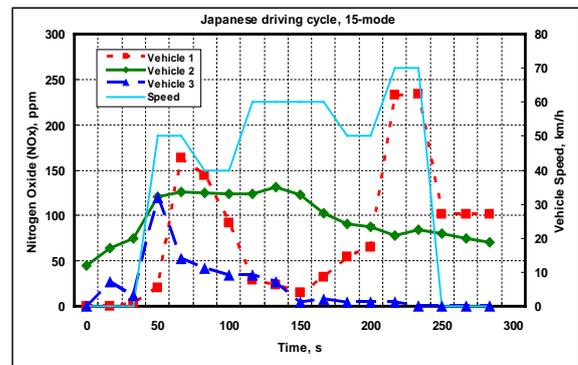


Figure 5. Time history of emission pollutant for nitrogen oxide (NO_x)

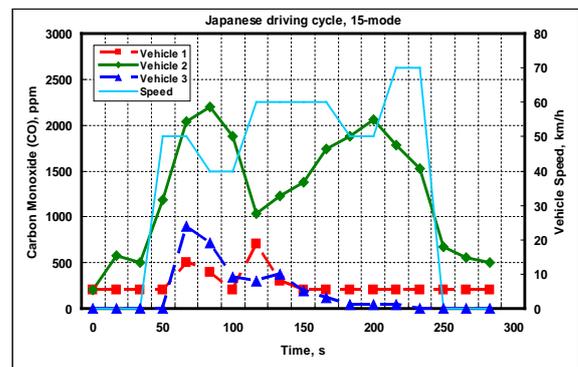


Figure 6. Time history of emission pollutant for carbon monoxide (CO)

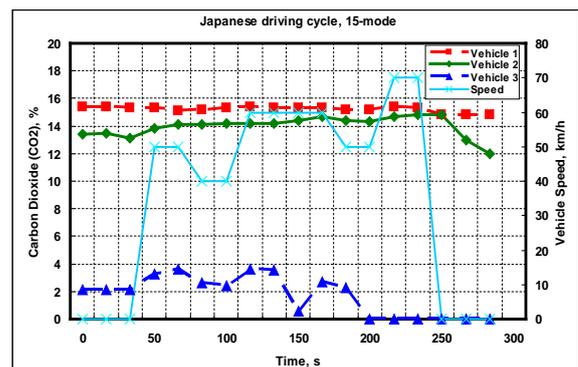


Figure 7. Time history of emission pollutant for carbon dioxide (CO₂)

4. Results and Discussion

4.1. On Laboratory Chassis Dynamometer Tests Results

The emission pollutants of NO_x, CO, CO₂ and HC measurements were conducted for Vehicles Nos. 1, 2 and 3 on the laboratory chassis dynamometer. The results of these measurements are presented in Figure 5, Figure 6 and Figure 8. Inspection of the data indicates profiles of emission pollutants concentrations measured, where are all not consistent with the profile of the driving cycle

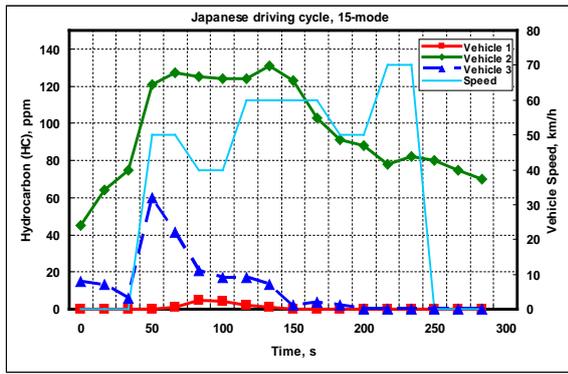


Figure 8. Time history of emission pollutant for hydrocarbon (HC)

The variability in the emission pollutants of NO_x, CO, CO₂ and HC measured for the three vehicles on the laboratory chassis dynamometer can be observed in figures. Except for CO₂ (Figure 6) and HC (Figure 8), the results show a relatively consistent with the profile of the driving cycle.

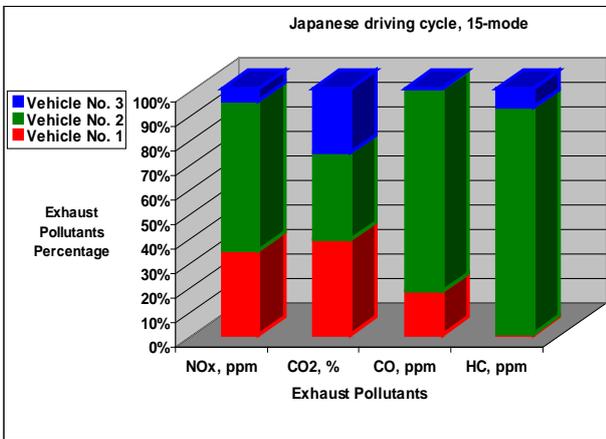


Figure 9. Emission pollutants percentage average

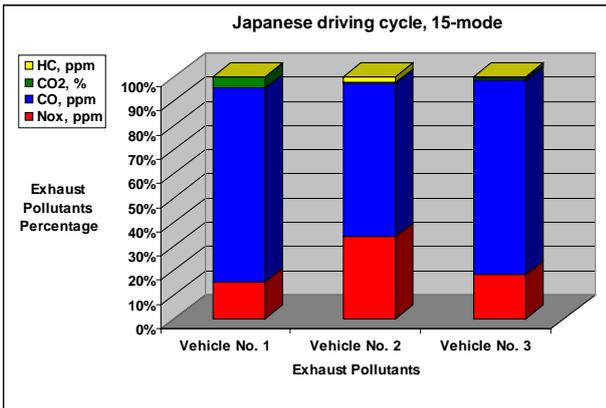


Figure 10. Vehicle number percentage average

In terms of average values, it can be seen that on one hand, the emission pollutants from Vehicle No.2 are in general much higher than to Vehicle No.1 and Vehicle No.3, and on the other hand, that there is a large variation in the emission pollutants reported in Figure 9 and Figure 10. The variation in the emission pollutants reported could be related to the differences in the conditions of the vehicles and differences in the combustion conditions for the vehicles, where the carbon to hydrogen ratio in the combustion, higher of the temperature and the air-fuel

ratio gets away from stoichiometric condition. As expected, vehicles are fueled with normal gasoline which is due to its cheaper price and availability in every gas station.

4.2. Predicted Fuel Consumption Results

The conversion from volume concentration of CO, HC, and NO measured on laboratory chassis dynamometer to their fuel-specific mass emission pollutants E_{CO} , E_{HC} , and E_{NO} based on equations (1) to (3), from which the fuel consumption of emission pollutants mentioned above are predicted in this study based on equation (5). In addition to the information existed in Table 1 and Table 2, Figure 11 to Figure 14 show the prediction of fuel consumption for all the three vehicles. By comparing the prediction for fuel consumption for each of the characteristics, the picture of their relevance for the fuel consumption gets clearer. Figure 15 and Figure 16 depicts the average values of fuel consumption at each emission pollutants along with the total values which show that similar effects have been observed between fuel delivery system, model year, accumulated mileage and curb weight. These four factors appear to be the most contributors to increased vehicular emissions levels. The total averages of fuel consumption are increased, where the percentage of total average fuel consumption at vehicle No. 1 is about 19%, is about 31% for vehicle No. 2 and is about 69% for vehicle No. 3.

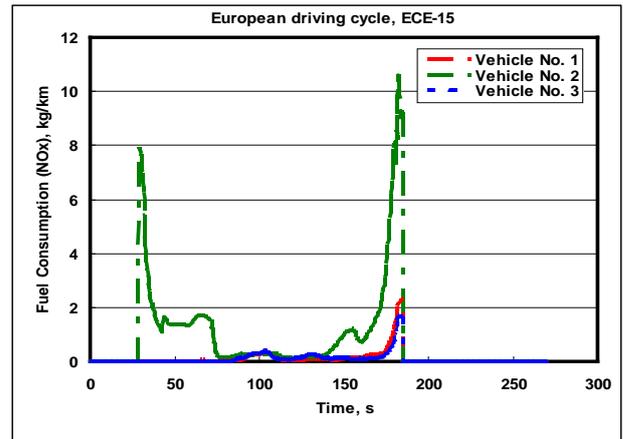


Figure 11. Time history of fuel consumption due to nitrogen oxide (NO_x)

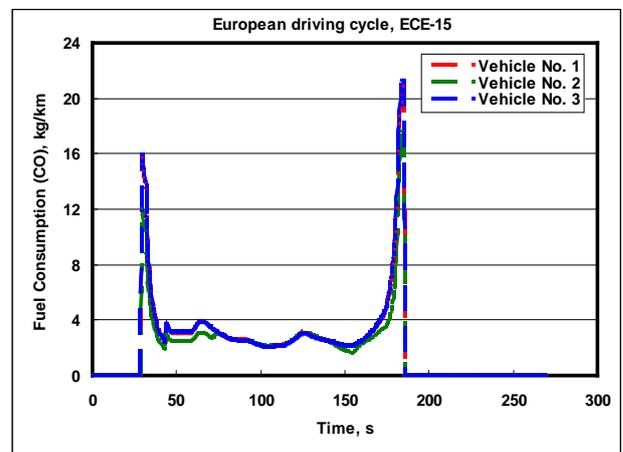


Figure 12. Time history of fuel consumption due to carbon monoxide (CO)

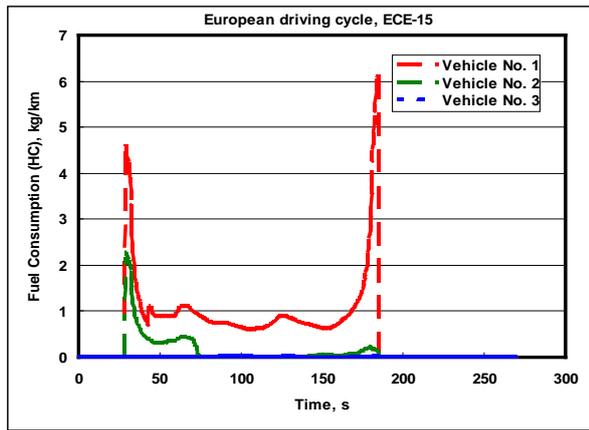


Figure 13. Time history of fuel consumption due to carbon dioxide (CO₂)

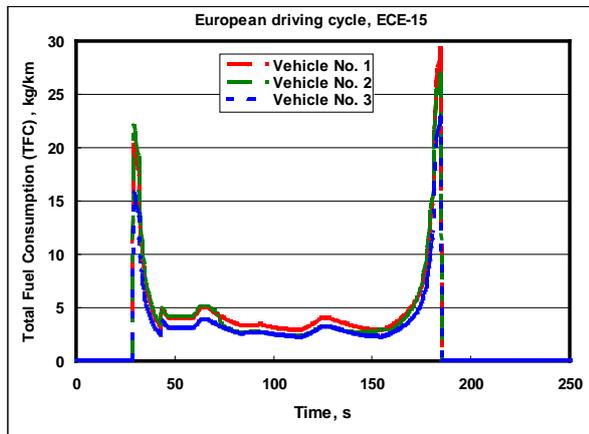


Figure 14. Time history of total fuel consumption

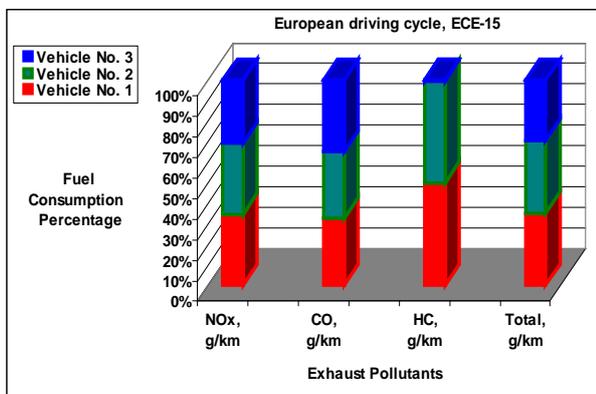


Figure 15. Averages percentage of fuel consumption

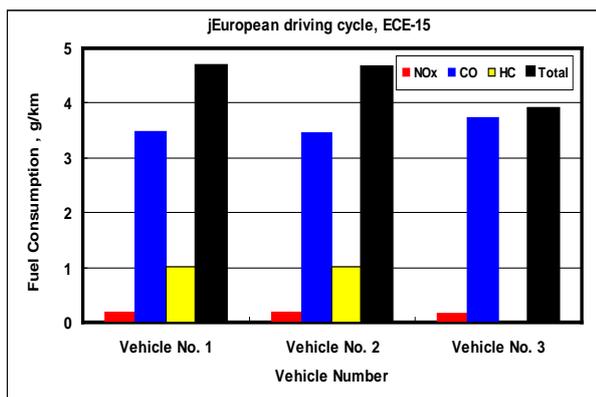


Figure 16. Vehicles fuel consumption average

5. Conclusions

1. There were significant differences for vehicle emission pollutants distributions, based on the standard driving cycle considered in this study. Therefore, it is necessary to improve the traffic situation to alleviate the emissions in cities of Egypt. There is no doubt that the new vehicle emission standards implemented recently have made great improvements on lowering the emission level per vehicle.

2. Using the fuel consumption based approach together with the measured emission pollutants in this work, the estimate of fuel consumption due to NO_x emission pollutant ranged between 0.116-4.139 kg/km, due to CO emission pollutant ranged between 2.288-8.964 kg/km and due to HC emission pollutant ranged between 2.440-10.893 kg/km.

3. The capability of estimate the influence of the impact of the driving mode, cruise velocity and type of vehicle on fuel consumption and pollutant emissions of a vehicle equipped with gasoline internal combustion engine is illustrated.

References

- [1] Esber, L. A., El-Fadel, M. and Shihadeh, A. "Comparison of trip average in-vehicle and exterior CO determinations by continuous and grab sampling using an Electro-chemical sensing method" Atmospheric Environment 41, pp. 6087-6094, 2007.
- [2] Yu, U. "Remote vehicle exhaust emission sensing for traffic simulation and optimization models" Transport Res.-D, Vol. 3, No. 5, pp. 337-347, 1998.
- [3] Gramotnev, G., Ristovski, Z. D., Brown, R. J. And Madl, P. "New methods of determination of average particle emission factors for two groups of vehicles on a busy road." Atmospheric Environment 38, pp. 2607-2610, 2004.
- [4] Silva, C., Ross, M. and Farias, T. "Analysis and simulation of 'low-cost' strategies to reduce fuel consumption and emissions in conventional gasoline light-duty vehicles" Energy Conversion and Management 50, pp. 215-222, 2009.
- [5] Al-Momani, T. M., Al-Taani, A. A., Al-Nasser, A. D. and El-Radaideh, N. M. "An assessment of automotive emissions in Irbid, northwest Jordan" Electronic Journal of Applied Statistical Analysis (EJASA), Vol. 4, Issue 1, pp. 91-102, 2011.
- [6] Abam, F. I. and Unachukwu, G. O. "Vehicular emissions and air quality standards in Nigeria" European Journal of Scientific Research 34, pp. 550 - 560, 2009.
- [7] Brown, J., King, F, Mitchell, W., Squier, W., Harris, D. and Kinsey, J. "On-Road Facility to Measure and Characterize Emissions from Heavy-Duty Diesel Vehicles" J. Air & Waste Manage. Assoc. 52: pp. 388-395, 2002.
- [8] Brusstar, M., Stuhldreher, M., Swain, D. and Pidgeon, W. "High efficiency and low emissions from a port-injected engine with neat alcohol fuels" Society of Automotive Engineers (SAE), Paper No. 2002-01-2743, 2002.
- [9] Tamsanya, S., Chungpaibulpattana, S. and Athajariyakul, S. "Development of automobile Bangkok driving cycle for emissions and fuel consumption assessment". The 2nd Joint International Conference on Sustainable Energy and Environment (SEE). 2006.
- [10] Patil, K., Khanwalkar, P., Thipse, S., Kavathekar, K. and Rairkar, S. D. "Development of HCNG blended fuel engine with control of Nox emissions" International Journal of Computer Information Systems and Industrial Management Applications (IJCISIM), Vol.2, pp.087-095, 2010.
- [11] Lakatos I."Elaboration Of A New Method For Developing A Diagnostic Procedure For Motor Vehicles Based On A Model" Periodica Polytechnica Transportation Engineering, Vol. 41, No. 1, Pp. 57-64, 2013.
- [12] Aslam, M. U., Masjuki, H. H., Kalam, M. A. and Amalina, M. A. "A comparative evaluation of the performance and emissions of a

- retrofitted spark ignition car engine" *Journal of Energy & Environment* 4, pp. 97-110, 2005.
- [13] Domanovszky H: Gas Propulsion Or E-Mobility Is The Solution On The Way Of Clean And Carbon Free Road Transportation?. *Periodica Polytechnica Transportation Engineering*, Vol. 42, No. 1, Pp. 63-72, 2014.
- [14] Pourkhesalian, A. M., Shamekhi, A. H. and Salimi, F. "Performance and emission comparison and investigation of alternative fuels in SI engines" *Society of Automotive Engineers (SAE)*, 2009-01-0936, 2009.
- [15] Taylor, P. C., Verkade, J. G., Gopalakrishnan, K., Wadhwa, K., & Kim, S. Experimental Studies On Development Of Sustainable Agricultural-Based Road Transport Deicing Applications. *International Journal For Traffic And Transport Engineering*, 4(2), 2014.
- [16] Yao, Z., Wang, Q., He, K., Huo, H., Ma, Y. and Zhang, Q. "Characteristics of real-world vehicular emissions in Chinese cities" *Journal of the Air & Waste Management Association* Vol. 57, pp. 1379-1386, Nov 2007.
- [17] Holmen, B.A. and Niemeier, D. A. "Characterizing the Effects of Driver Variability on Real-World Vehicle Emissions" *Transport Res. D*, 3, pp.117-128, 1998.
- [18] Jiménez J.L.; McClintock P.; Mcrae G.J.; Nelson D.D. and Zahniser M.S. "Vehicle Specific Power: a Useful Parameter for Remote Sensing and Emission Studies" 9th CRC On-Road Vehicle Emissions Workshop; San Diego, CA, 1999.
- [19] Koupal J.; Nam E.; Giannelli B.; Bailey C." The MOVES Approach to Modal Emission Modeling" 14th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 2004.
- [20] Tamás Andrejszki, Miquel Gangonells, Eva Molnar, Ádám Török, ForFITS: a New Help in Transport Decision Making for a Sustainable Future *Periodica Polytechnica Transportation Engineering*, Vol. 42, No. 2, pp. 119-124, 2014.