ESTIMATE OF EMISSION COEFFICIENTS FROM VEHICLES IN ISRAEL

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ABSTRACT

The paper presents the results of a research project aimed at estimating emission coefficients from passenger cars in Israel. The results were obtained by measurements of pollutants concentration in three driving modes: at idle, while driving in city center and at constant vehicle speeds typical of inter-urban and suburban driving. The measurements were carried out by conventional methods using gas-analyzers and chemical procedures and also by employing remote sensing equipment. Based on these results, an initial estimate has been made of emission coefficients representative of the three driving modes. A combined emission coefficient is suggested and has been compiled describing general pattern of emissions from a vehicle per distance traveled.

INTRODUCTION

The motorization rate growth in Israel is one of the highest in the world. The number of vehicles in the country has risen about 20 times from 1960, [1]. This growth brings about an enormous increase of air pollution. According to figures released by the U.S. Environmental Protection Agency (EPA), conventional internal combustion engine vehicles currently contribute 40% - 50% of ozone, 80% - 90% of carbon monoxide and 50% - 60% of toxins found in urban areas, [2]. In Israel, it has been reported for example that the contribution of CO emission from motor vehicles is about 90%, [1]. The concentration in the air of CO and the other pollutants frequently exceeds the allowed maximum, as a result of topographic and climatologic conditions such as stagnant areas in "great urban canyons" between sky scrapers. One of the main causes of high CO levels is congested traffic with jams and "stop and go" situations in city centers. Therefore the issue of emissions control and limitation is very important.

The establishment of emission standards and the estimate of emission coefficients are strongly related to accurate evaluation of zonal pollution or of total pollutants inventories. The results of such evaluations can serve, in addition, to air quality predictions, also for the design of new urban transportation systems and of ventilation systems for closed parking areas, tunnels etc. For example, traffic control can optimize vehicle speed, by "intelligent" or "fuzzy" logics, so as to minimize total emission of pollutants, [3]. In this way, road safety is enhanced directly and also indirectly by lower exposure of drivers and pedestrians to the toxic substances in the exhaust gases. It is known that the toxicity causes increase of the reaction time, which is essential for normal and safe behaviour on the road.

Different methods were used to determine vehicle emission factors and to evaluate emission inventories. Such methods are based on vehicle emissions measured on chassis dynamometer, fleet tests on controlled track test, constant speed tests characteristic for interurban road traffic and idling tests. All these methods are based on fuel consumption and emissions measurement. A recent advance in the field of emission measurement from vehicles is the introduction of remote sensing. This method can be used to define average emission values and/or to directly identify "big polluters" during on-road traffic. However, it has been reported, e.g. [3 - 5], that the emission concentration results obtained with this technology are often inconsistent with emission measured by standard equipment. It is estimated that currently the accuracy of the remote sensing measurements is of the order of 5% for CO and 15% for HC. However, the technology is still being developed, and furthermore, the remote sensing system has the advantage of a very high productivity because hundreds or thousands of cars can be tested daily.

Measurements performed on chassis dynamometer are accurate but the high cost and the low productivity of this method limits its use. On-board measurements done with a complete set of apparatus located inside the vehicle in real conditions of traffic are precise, and they have the advantage of relatively low cost, but the work volume is large, thus productivity is limited. Idling tests are also very important, because of the great number of cars which can be tested during a short time, and the widespread use of this test in many car maintenance systems. These tests can provide general indication of the engine tune-up, several attempts have been made to relate vehicle emissions at idling and the driving cycle pollution measurements, cf. [6].

The goal of the research work described in this paper was to estimate emission coefficients of gasoline private vehicles in Israel. The presentation here includes results and analysis of the experiments performed in this work: measurements of pollutants emission at idle, at constant speeds typical of suburban and inter-urban driving and of city-center traffic. The measurements were carried out by conventional methods and also by remote sensing. A more comprehensive presentation, which includes all the measured data, appears in [1].

METHODOLOGY

Several factors determine the amount of pollutants emitted from vehicle engine: engine and vehicle design, age, mileage accumulation, rates and maintenance level, type and quality of the fuel, driving velocity and pattern, road and weather conditions, etc. Other traffic parameters, such as acceleration, deceleration and proportion of stand-still time also affect the exhaust emission composition. Some of these were studied in the research work described below.

Statistical data and analysis. The first stage of this work included analysis of statistical data related to the Israeli vehicles fleet, like vehicle age, engines displacement and production year. These data were grouped in accordance with each period of the same EEC pollution limitation regulations, such that it was possible to determine the vehicle fleet sample, to measure emissions and to obtain the mean emission factors.

Idling tests. The idling tests were performed on 362 vehicles, a representative sample of Israeli vehicles fleet. The tests were performed after warm-up of the vehicle engine and the three way catalyst (TWC). Concentration of CO, HC an d CO_2 in the exhaust gases were measured in this series of tests using a standard NDIR four-gases analyzer.

City realistic driving conditions and fuel economy. To simulate the Israeli city driving conditions, a route of 5.5 km was chosen in the city center of Haifa, [7]. In ref. [7] it was mentioned that the Israeli driving cycle found in 1980 was very similar to the European driving cycle and this selected route was recognized as representative. The driving pattern can generally be characterized by parameters such as: average speed, mean acceleration, mean deceleration and stand-still time. Among them the average speed is the one most often used to present emissions and fuel economy vs. changes in driving pattern. About 60 tests were performed during working days from 7:00 AM until 7:00 PM in order to update this parameter. Ten different cars with engine displacement from 770 cc. up to 2000 cc. participated in these tests representing the composition of the car fleet in Israel. The fuel consumption was measured by gravimetric method, using equipment which was installed on-board. A part of the experimental data and results was published previously by [8]. Fuel economy measurements were performed with and without air conditioning (AC), after the warm-up of the engine and a run up of approx. 25 km to stabilize the engine, axle and transmission temperature.

Constant speed tests. On board of each car during the constant speed test were installed the following test facilities: gravimetric system for the fuel consumption measurement, gas analyzer, devices for the car speed and engine speed measurement, and exhaust sampling system for the NO_x concentration determination in the laboratory. The tests were performed on the same highway segment of 5 km length. For each test the cars were driven in opposite directions to minimize wind and grade effects. These tests were performed at two different vehicle speeds, 50 and 90 km/h.

Remote sensing (RS). In order to obtain real-time data of many on-road vehicles emission, a series of tests was performed with a remote sensing system developed by Remote Sensing Technologies Inc. (RSTI). The hardware consists of three basic units: a source, a detector and a computer. Infra-red and ultra- violet light absorption in the medium between the source and the detector (the exhaust gases plume) is used to determine the level of pollutants emissions. Using a video camera during the data collection allows the registration of a license plate of each vehicle tested, and as result its model and production year may be ascertained.

The tests were performed together with the RSTI specialists, on a flat road in Haifa, in a single lane traffic flow, where the average speed of vehicles was 40 to 50 km/h. The system gives tailpipe the concentrations of CO, CO_2, HC for every car, and in addition the instantaneous speed of the car. Over 700 vehicles were tested this way.

RESULTS AND DISCUSSION

Statistical data and analysis. The Israeli gasoline vehicle fleet consisted of about 1.2 million vehicles with about one third of them equipped with TWC. The age composition is the following: under 4 years old - 39%, between 5 - 9 years old - 31%, between 10 - 19 years old - 27%, more than 20 years old - 3%. The number of uncontrolled emission cars (up to 1969) represents less than 1%. By engine displacement the distribution is: up to 1000cc - 11%, 1001 - 1600cc - 78%, 1601 - 2000 cc - 8% and more than 2001cc - 3%, [9]. It is necessary to underline the similar composition of the fleet sample tested with the RS (about 700 vehicles) and the statistical data for Israeli vehicles fleet. The RS fleet sample composition was the following:

By year production	**By engine capacity**
1.5% < 1980 included	3.5% < 1000 cc
9.9% 1981 - 1985	32,8% 1000 - 1400 cc
21.5% 1986 - 1990	42.2% 1400 - 1600 cc
51.8% 1991 - 1995	13,2% 1600 - 2000 cc
15.3% 1996 - present	9,3% > 2000 cc

Idling tests. The results from Figure 1 show that 67% of vehicles tested meet the EEC 52/92 Directive requirements.

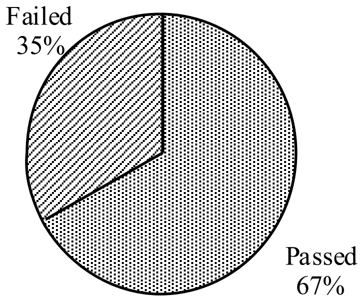

Figure 1. Idling tests results

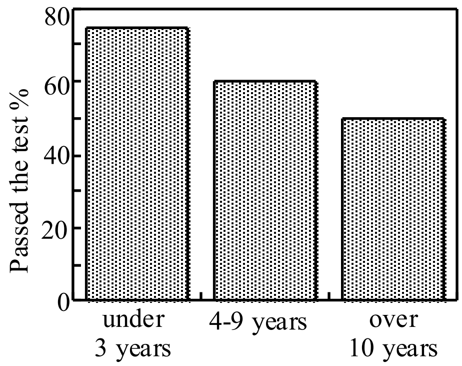

Figure 2. Percentage of vehicles which passed the idling test.

Figure 2 presents the percentage of vehicles which passed the idling test depending on production year, for engine capacities between 1000 and 1600 cc. As expected, the number of old vehicles "out of limit" is bigger than for new cars.

City Center Driving Cycle. It was found that the average speed of today's city center cycle is 15,3 km/h, a substantial decrease about 30% compared to 21.8 km/h which was estimated in 1980, [7]. Also the fuel consumption increased by 34 - 38%, when the average speed dropped from 19 km/h (morning average speed) to 10.5 km/h (noon average speed). This means 15% increased fuel consumption for 30% reduction of average speed. The use of AC is accompanied by fuel consumption increase by an average of 20%, [8].

Figure 3 presents the urban driving emissions variation with car age, for CO, CO_2, HC and NO_x. The decrease of CO, HC and NO_x after 1990 followed from the introduction, at that time of TWC in vehicles.

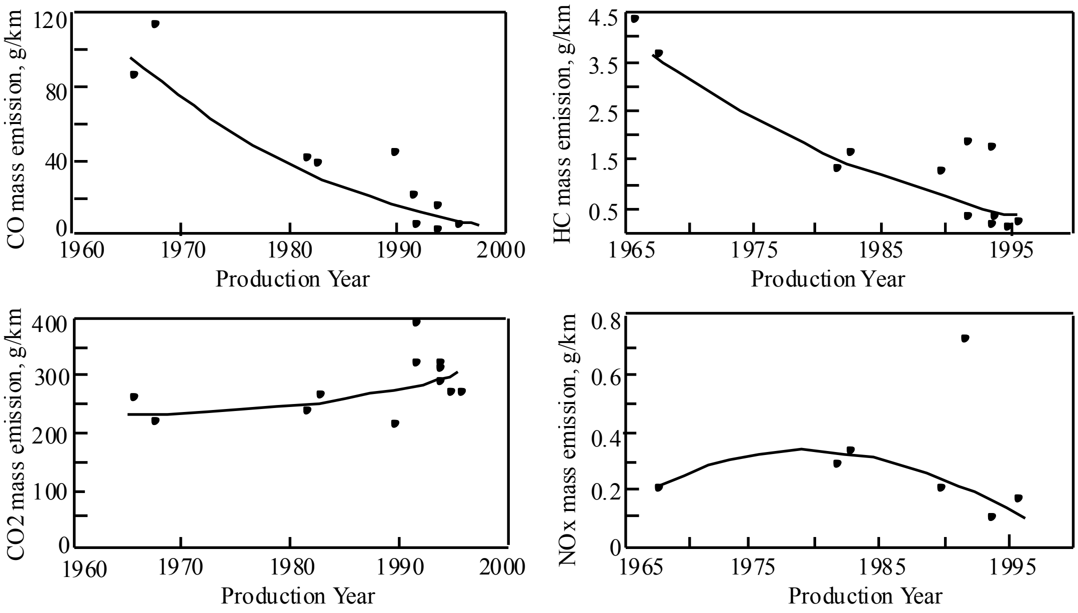

Figure 3. Average emissions in urban cycle as function of production year.

Constant speed tests. The CO mass emission test results for two different vehicle constant speeds, 50 and 90 km/h are shown in fig. 4. The tests performed under the above mentioned conditions show that the CO average emission for cars made in the '80s is ten times higher than that for the '90 car with TWC. The same trend is observed with the HC emissions, which are twenty times higher for '80s cars compared with '90s cars with TWC. As for NO_x emissions, the new cars with TWC pollute thirty times less than the '80s cars or '90s car without TWC. The results clearly show the importance of TWC for the reduction of the emission. The problem which must be considered very carefully in the future is the life time of the TWC, and to establish a suitable deterioration factor for it.

The results correlate with those found for urban driving cycle, i.e. reduction of emissions for the '90s cars.

Remote sensing (RS). Figure 5 presents the results obtained for car engine displacement between 1400 and 1600 cc, which represent 42% of fleet sample.

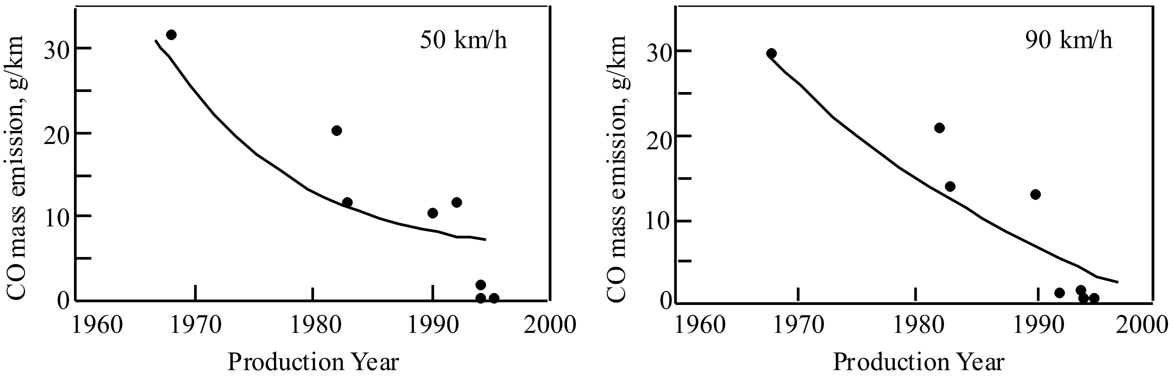

Figure 4. Time evolution of CO emission for constant speed.

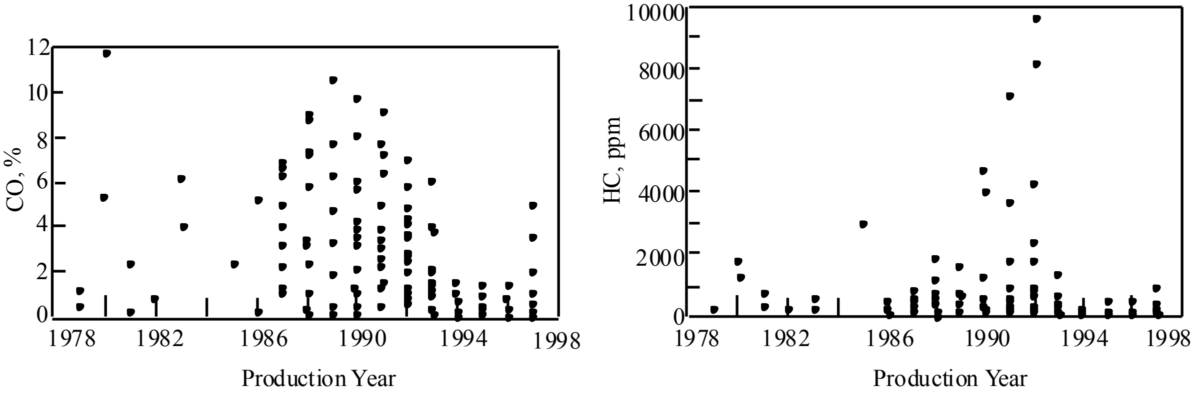

Figure 5. Distribution of the tests results for CO and HC emissions as function of the production year.

Rather a large number of tests which can be performed by using RS enables to detect and identify vehicles that are "big polluters". It was found that about 10% of the cars tested contribute about 50% of the total amount of pollutants. Figure 6 shows this contribution for CO and HC emissions.

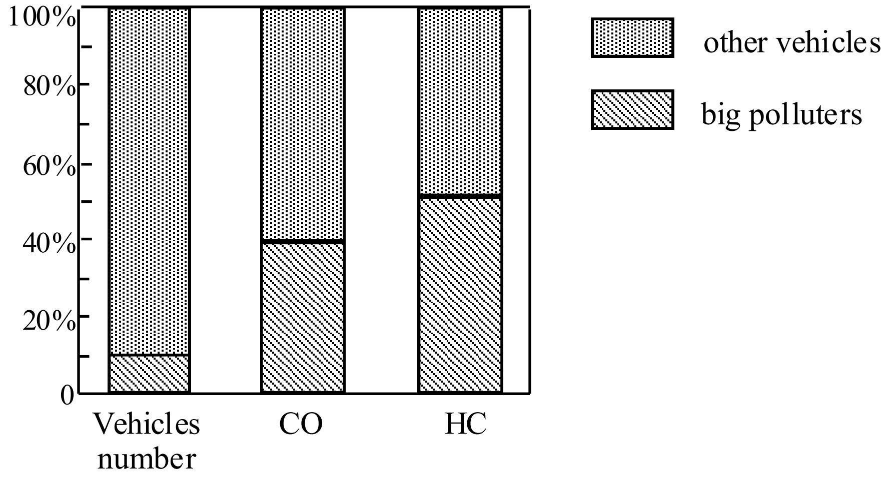

Figure 6. The contribution of "big polluters" of CO and HC emissions in the sampled fleet.

These results are well correlated with those obtained by others, [10], and indicate clearly that the RS is one of the effective ways to improve air quality.

EMISSION COEFFICIENTS

The main purpose of experimental testing performed in this program was to evaluate emission coefficients for CO, HC, NO_x and CO_2, depending on the age of the vehicles and engine displacement. These emission coefficients, in g/km, multiplied by the estimated number of cars for a specific period of time (or car ages), multiplied by the annual average traveled distance, gives the annual total emission. For example for a specific pollutant i the annual emission quantity of it can be calculated according to:

$$M_i = E_i \cdot N_v \cdot M_{av} \cdot 10^{-6} \text{ [t/year], where} \qquad (1)$$

M_i - Annual emission quantities for each specific pollutant i , for each vehicle age class.
E_i - Emission coefficient for each specific poollutant i, [g/km];
N_v - Number of vehicles for a specific age class.
M_{av} - Annual average mileage for one vehicle [km].

The emission coefficients E_i of CO, HC, NO_x and CO_2 for each vehicle age class was calculated by the following:

$$E_i = 0.45E_n + 0.28E_f + 0,27E_{dc}, \text{ [g/km] where} \qquad (2)$$

E_n - emission coefficient for 90 km/h constant speed typical of interurban or suburban travel calculated from data of the constant speed tests.
E_f - emission coefficient for 50 km/h constant speed typical of urban residential area calculated from data of RS.
E_{dc} - emission coefficient in heavy urban traffic calculated from data of city center

driving cycle.

The weight of each emission coefficient in the algorithm (2) was established in conformity with statistical data regarding the specific behavior of the Israeli fleet, [9]. The coefficients in eq. (2) correspond, respectively, to 45% interurban travel, 27% city center travel and 28% typical urban residential routes (55% urban travel). In this way, emission coefficients were established for every fleet group by production and engine displacement. Averaged emission coefficients only by production year were also calculated. The example of these data are shown in Table 1. Detailed results of emission coefficients evaluation together with the list of main assumptions may be found in the report [1].

Table 1. Emission coefficients "Ei" for each vehicle age class.

Ei [g/km]/Prod year	CO	HC	NO_x	CO_2
- 1976	66	2.80	2.20	158
1977 - 1984	37	2.30	2.40	174
1985 - 1988	28	2.00	2.50	172
1989 - 1992	21	1.90	2.65	175
1992 - TWC available	64	0.35	0.26	192

The total amount of CO, HC, NO_x and CO_2 can be obtained by adding the specific values found for every age class, by the expression:

$$M_{T_i} = \sum_{1}^{n} M_i \, [t/year], \quad \text{where}$$

M_{T_i} - total mass for each pollutant i.

M_i - total mass for each pollutant/vehicle age class, [t/year].

n - number of vehicle age classes.

CONCLUSIONS

The results of the study on emissions from passenger car engine are very important for future studies or design regarding urban areas, highways, covered parkings, tunnels, vehicles, traffic optimization, health problems and the policy regarding the development of new cleaner energy sources for vehicle engines and transportation systems.

The study shows that the composition of the fleet is very important. A small percentage, 10 - 15% of fleet, produces 50% or more of the total pollution. This part of the fleet is mainly composed by old cars over ten years of age.

The precise evaluation of the emission coefficients for each pollutant substance is very important in the process of establishment of the pollutants inventory. By knowing these coefficients, it is possible to estimate, with high precision, the fraction of emissions in the pollutant emission quantity in a specific area or for the whole country in a specific period of time, or the contribution of each vehicle age class.

This study emphasizes also the importance of the TWC to reduce drastically the pollutant emission. The observed reduction of pollutants mass emissions were about 80% for CO and NO_x and 85% for HC, [8].

It is perfectly clear that for all these reasons, the knowledge of the pollutant emission composition of gasoline powered vehicles and the factors which influence this, are very important for the present time and also for the future.

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