Transport and Air Pollution, 5th Int. Sci. Symp., Avignon, France, June 2000

The effect of road profile on passenger car emissions

Leonid TARTAKOVSKY*, Marcel GUTMAN*, Yuri ALEINIKOV*, Mark VEINBLAT*, Yoram ZVIRIN*, Bernanda FLICSTEIN** & Bella BEN DAVID**

*Internal Combustion Engines Laboratory, Faculty of Mechanical Engineering
Technion – Israel Institute of Technology, 32000 Haifa, Israel -
Fax +972 4 8324 533 - email: meryzlt@tx.technion.ac.il
** Association of Haifa Region Municipalities for Environment, Israel

Abstract

The paper presents experimental results of on-road measurements of vehicle fuel consumption and exhaust emissions for various road gradients. Gasoline-powered passenger cars of different technologies were tested at various speeds relevant for urban driving.
The response of vehicle emissions to road slope was evaluated for roads with gradients of up to ±10 %. Concentrations of CO, HC and NOx in the exhaust gases were measured, and their mass emissions were calculated. Correction functions for emission factors of gasoline passenger cars have been developed.
Key-words: *emissions, fuel consumption, passenger car, road gradient.*

Introduction

Emissions of pollutants from motor vehicles during city-center driving contribute significantly to the total air pollution inventory. Different driving cycles are commonly used in order to simulate driving patterns of vehicles under various traffic conditions, Andre (1996). In most of these cycles, driving on plain road is assumed. However, road gradient is an important factor influencing vehicle emissions and may have a major effect on the emission levels for some geographical areas.
The slope of a road affects the resistance of a vehicle to traction and therefore leads to an associated increase or decrease in engine power required. It is emphasized that even when considering large-scale inventory systems, it cannot be assumed that extra emissions during uphill driving will be compensated by a corresponding reduction at downhill driving, Hassel and Weber (1999).
In the majority of the published research works which deal with the effects of road gradients on emissions, the slope range is limited to ±6 %, which is typical for their road networks, Boulter & Cox (1999), Hassel & Weber (1997), Keller et al. (1995).
The specific topography of some major Israeli cities, such as Jerusalem and Haifa, results in a high percentage of roads with gradients much steeper than ±6 %. The main reasons of the research work whose findings are presented in this paper, were the need for local emission estimates in these areas, and the gaps in knowledge and existing data about gradient factors for steep slopes.

1. Road gradients pattern

Special series of detailed slope measurements were carried out in order to estimate the typical distribution of road gradients in Haifa. These results supplemented the information available from municipal sources and allowed the authors to perform the estimate of road gradients distribution, shown in Fig.1. As can be seen, about a quarter of the urban roads in Haifa have slopes steeper than

±6 %. Maximal average values of road gradient were found to be 11%, but a significant amount of road segments with lengths of some hundreds meters and slopes of 16% have also been noted.

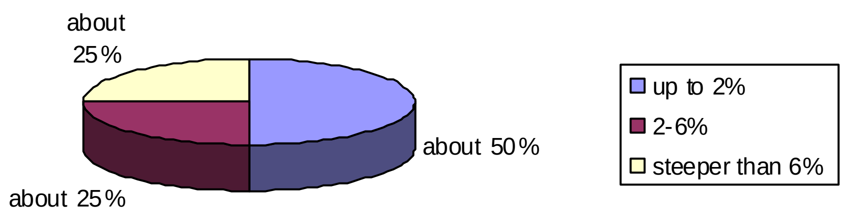

Figure 1: Estimate of road gradients distribution in Haifa.

2. Test methodology

The experiments of road gradient effects on car emissions and fuel consumption were carried out on carefully selected road segments, meeting the following criteria: constant road slope along the segment (gradient variation not exceeding ±0.5 %); absence of traffic lights; minimal curvature of the segment and sufficient length; at least two lanes and no heavy traffic; good and uniform quality of road surface. Gradient values of the segments selected for the tests were 0, 4, 8 and 10%.
The experiments were carried out on four passenger cars with spark-ignition engines: 3 with three-way-catalyst (TWC) and controlled air/fuel mixture and one conventional carburettor car. The vehicles selected for the tests are of models typical for the Israeli fleet. The response of vehicle emissions to road slope was compared for vehicles with single-point (SP) and multi-point (MP) injection systems, as well as for aged and fresh catalysts. Some technical data of the cars, which were involved in the emission tests, are presented in Table 1.

Car No.	Production year	Traveled distance, km	Engine displacement, cc	Type of fuel system	TWC availability
1	1988	180,000	1300	Carburettor	No
2	1994	100,000	1400	SP injection	Aged TWC
3	1999	25,000	1400	SP injection	Fresh TWC
4	1999	20,000	1600	MP injection	Fresh TWC

Table 1: Cars used for emissions and fuel economy tests.

It is noted that cars 2 and 3 with aged and fresh catalysts are of the same make and model. All fuel economy and emission measurements were performed with fully warmed-up engines.
In order to reduce the number of factors influencing vehicle emissions and to single out the effect of road gradient, it was decided to perform the tests at constant speeds typical for urban driving. The vehicles were therefore tested at the speeds of 20, 40 and 60 km/h on each road gradient.
In all experiments, car fuel consumption and emissions of CO, HC and NO_x were measured. Fuel consumption was evaluated by an accurate gravimetric method. The engine feeding and return fuel pipes were re-connected with an additional fuel pump to a special fuel tank, which was precisely weighed in the laboratory before and after the test, with accuracy of ±1 g. The accuracy of the fuel consumption measurement is estimated as better than 0.5%.

Exhaust gases emitted during each test were sampled on-board through appropriate filters and valves, and collected into a special bag intended for this purpose. Immediately after the test, CO and HC contents in the bag and lambda values (λ) were measured by a standard NDIR gas analyzer, usually used for inspection/maintenance tests. NO_x concentrations were measured by using a chemiluminescent laboratory gas analyzer.
Based on the results of fuel consumption and emission measurements at various test conditions, appropriate gradient factors were calculated. The gradient factor (GF) is defined as the emissions (fuel consumption) ratio according to the formula: GF = E_I (FC_i) / E_0 (FC_0), where E_I (FC_i) is the emissions (of any pollutant) or fuel consumption at gradient "i" and E_0 (FC_0) is the emissions or fuel consumption at gradient 0%.

3. Results and discussion

Results of gradient factors variation as function of road slope for fuel consumption and emissions of CO, HC and NO_x, received for TWC-equipped and non-catalyst cars are presented in Figs. 2-5.

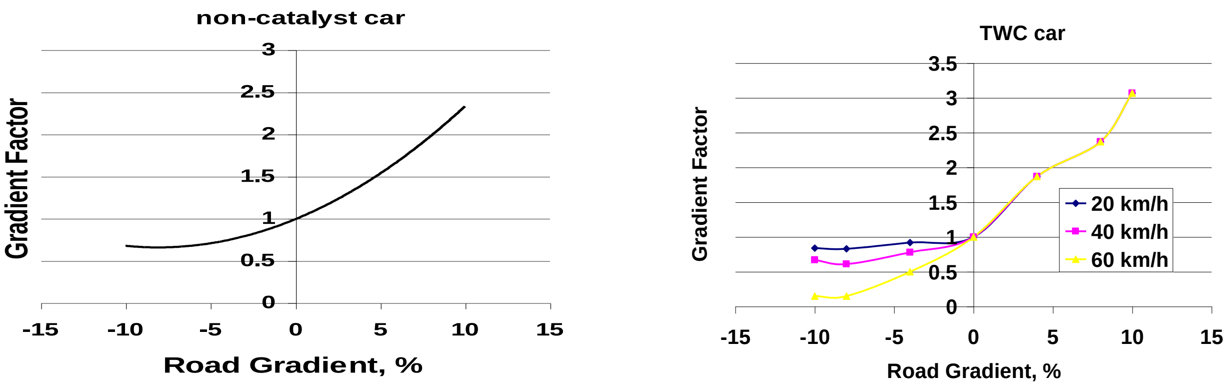

Figure 2: Gradient factors for fuel consumption.

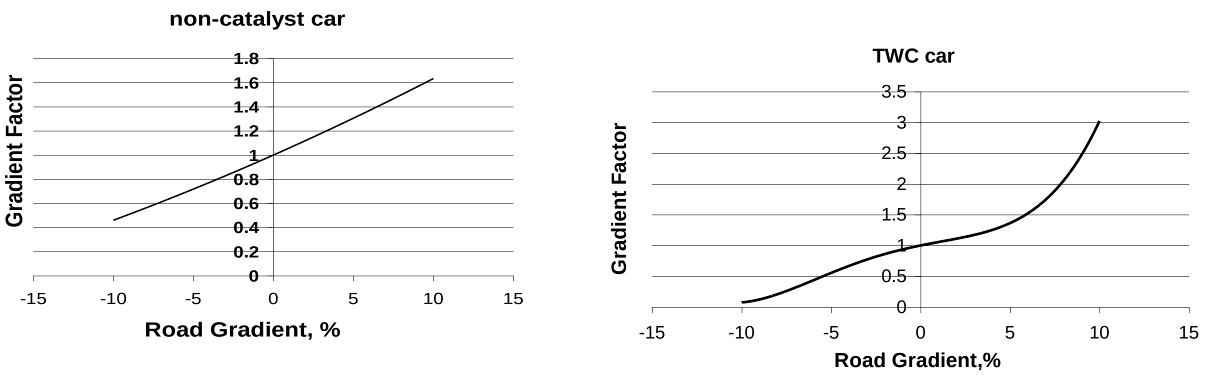

Figure 3: Gradient factors for CO emissions

.

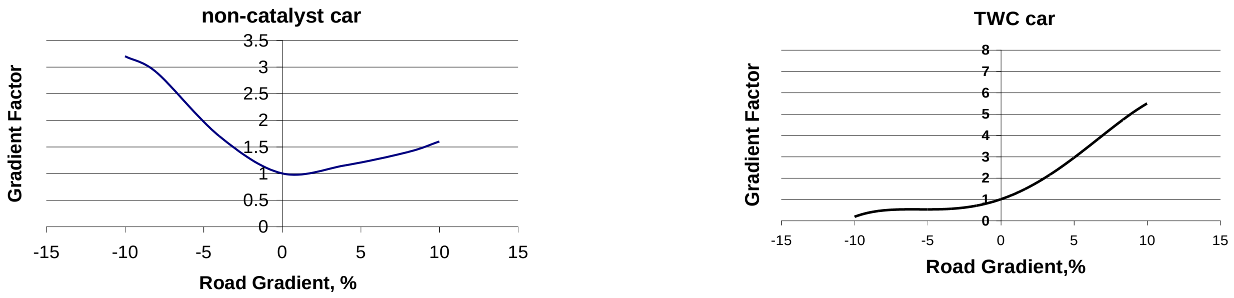

Figure 4: Gradient factors for HC emissions.

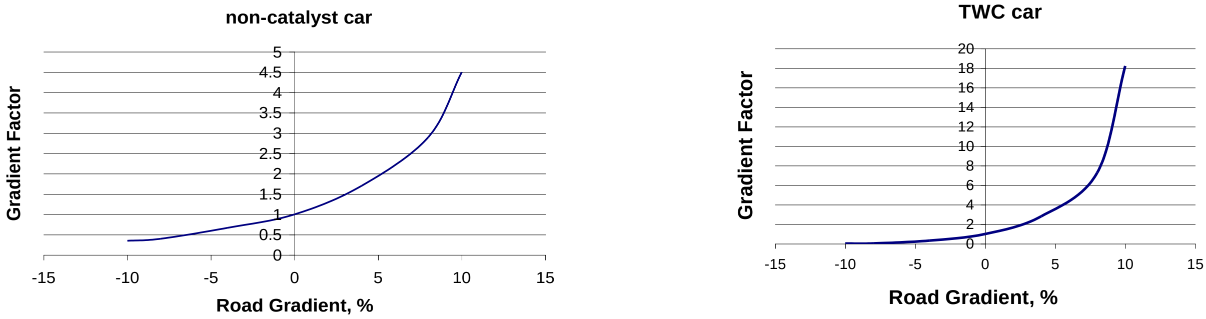

Figure 5: Gradient factors for NOx emissions.

No significant differences have been found in the response to road gradient of fuel consumption for catalyst and non-catalyst cars, at various speeds during uphill driving. At downhill driving, a significant difference was observed in fuel consumption behavior between conventional carburettor and TWC-equipped cars with fuel injection system. It was found that at vehicle speeds above 40 km/h and road gradients steeper than –5%, the influence of the phenomenon of overrun fuel-cut becomes appreciable, and leads to significant reduction (up to zero) of fuel consumption and, therefore – of exhaust emissions, both denoted by FC, (see Fig. 2). As can be seen from this Figure, despite this fuel-cut, the extra fuel consumption of a TWC car, when driving uphill, is not balanced by a corresponding reduction in fuel consumption when driving downhill. As can be seen from Fig. 4, a rise of HC emissions with increase of road gradient was observed at downhill driving for carburettor cars. A possible reason for this phenomenon is over-leaning of the fuel/air mixture at some engine speeds, in case of driving with closed throttle. Detailed measurements on more cars are needed in order to validate these observations. An additional fact that was noted and requires further validation and explanation, is that the response of TWC car emissions to change in road gradient is more sensitive compared to carburettor cars. One possible reason for it, that has to be checked, is variation in conversion efficiency as a function of exhaust gases flow rate.

A strong monotonous effect of vehicle speed was observed only for TWC cars with fuel injection at downhill driving, see for example Fig. 2 for fuel consumption. For the emissions in this case, and for speed - dependent fuel consumption and emissions in other cases, weighted average values of the gradient factors can be derived for use in specific calculations. Those in Figs. 2-5 were employed for estimates of emissions inventories in several Haifa regions, Tartakovsky et al. (2000).

Conclusions

Based on the results obtained in the road tests, the following conclusions have been reached. Road gradient is one of factors significantly affecting emissions from motor vehicles in some major Israeli cities. In Haifa, about 25%. of the roads have slopes steeper than 6%. At downhill driving, a significant difference was observed in fuel consumption behavior between conventional carburettor and TWC equipped cars with fuel injection system. It was found that at vehicle speeds above 40 km/h and road gradients steeper than –5%, the influence of the phenomenon of overrun fuel-cut leads to significant reduction (up to zero) of fuel consumption and, therefore – of exhaust emissions.

Additional tests are needed to further compare the effect of the road gradient on emissions from non-catalyst and TWC car.

Acknowledgement

The research work was financed by the Foundation for Environment Quality, Haifa, whose support is greatly appreciated.

References

Andre M. (1996): Driving cycles cevelopment: Characterization of the methods. SAE Technical Paper 961112.

Boulter P.G. and Cox J.A. (1999): A Review of European emission measurements and models for diesel-fuelled buses. TRL Report No. 378, Crowthorne, UK.

Hassel D. and Weber F. J. (1997): Gradient influence on emission and consumption behavior of light and heavy duty vehicles. TUV Rheinland report, No. 376013/09, Cologne, Germany.

Hassel D. and Weber F. J. (1999): Gradient influence for light-duty and heavy-duty vehicles – In COST 319: Estimation of Pollutants Emissions from Transport, Final Report of the Action, edited by R. Joumard, European Commission, Directorate General Transport, Luxembourg, pp. 38-40.

Keller M., Evequoz R., Heldstab J. and Kessler M. (1995): Luftschadstoff – Emissionen des Strassenverkehrs 1950 – 2010. Schriftenreihe Umwelt, No. 255, BUWAL, Bern, Switzerland.

Tartakovsky L., Zvirin Y., Gutman M., Aleinikov Y. and Veinblat M. (2000.): Estimate of pollutants emissions from motor vehicles in the Haifa Metropolis. Final Report to the Foundation for Environmental Quality, Project No. 034-149, Faculty of Mech. Eng., Technion, Haifa, Israel.