ACME IASI 2004: METHODOLOGY OF EMISSION FACTORS ESTIMATION FOR BUSES IN ISRAEL

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Abstract
One of the most difficult problems, which environmental specialists in the field of air quality are faced with, is the evaluation of air pollution by mobile sources. Various reviews and scenarios, that are carried out today, are frequently based on emission factors from abroad (usually European or USA data) that do not represent adequately the situation in Israel, because of two main reasons:

- *Different composition of the vehicle fleet;*
- *Different traffic and climate conditions.*

This work contains a description of the methodology, which was used to estimate emission factors for buses in Israel. Due to equipment limitations, we are forced to use the method, which was developed in the Technical University of Graz.
This method is based on using the results of type approval emission measurements (emission, power and fuel consumption) according to the ECE R49 standard 13-mode cycle, with addition of adapted weighting factors (AWF), which are obtained for real driving conditions in Israel. The AWF were calculated based on the results of real world driving behaviour measurements of buses.
In these experiments the parameters like: the bus speed, the bus engine's speed and engine load were measured in real driving conditions.

Key-words: *engines buses emissions, buses emission factors.*

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 30 times from 1960, [1]. In the last years was registered, also, a substantial rise of buses on the roads, especially, in urban areas. So, from about 8800 buses in 1990 there are now in Israel about 12000 buses. This growth brings about an enormous increase of urban air pollution. Concentration of pollutants in the air 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.
Before the late 80's the contribution from heavy-duty vehicles (gross weight $\geq$ 3500 Kg) to the total pollution caused by traffic, was not accurately assessed. Emphasis had until then been on light-duty vehicles, which were responsible for a far greater contribution to the total pollutions at that time, especially the case with regard to CO

and HC, the first pollutant to attract attention. However, with the introduction of the three way catalyst for passenger cars, as well as the ongoing increase in heavy-duty vehicles use, the emissions contribution of heavy-duty vehicles is becoming more significant [2,3]. Therefore the issue of emissions control and limitations is very important.

Because the very great mileage of the buses and the increasing traffic congestion which causes reduction of the average speed and leads to traffic jams, the buses pollution contribution is very important. To calculate the buses pollutants quantity for zonal air pollution or for total pollutant inventories, is necessary to estimate the buses emission factors. The principal problem in the definition of emission factors is to generate figures that represent emissions that are produced during real-world service. Emission factors are expressed usually in absolute units of for instance [g/Km] or [g/hour].

There are various reasons for need in emission factors for buses. The most important being [3,4]:

- To evaluate zonal pollution or total pollutants inventory.
- To make a comparison of emissions from buses with other emission sources possible.
- To provide an input for diffusion models that calculate the environmental impact of vehicles.
- To render the opportunity to define cost penalties for emitting harmful exhaust gases.
- To assess the cost-effectiveness of emission reduction technologies (like aftertreatment devices, electric or hybrid buses, etc.).

For the last points it is possible to take into consideration the external costs of the pollutant emissions, which result in damage to human health, buildings and crops. For typical urban conditions, the approximate costs of vehicles exhaust emissions (per one tone of pollutant) are: CO = 500 Euro; HC = 900 Euro; NOx = 10,000 Euro; PM_{10} = 20000 Euro; [5].

Actual emission levels from buses are a function of several variables, such as driver behaviour, traffic characteristics, air conditioning (AC) operation and vehicle parameters.

Due to the growing importance of heavy-duty vehicles in the total air pollution caused by traffic, the specialists in this field of activity have tried to solve this problem. For example, the German, Austrian and Swiss authorities completed an extensive research programme called the "Heavy Duty Emission Factors Programme". This programme is based on engine emissions maps of a representatives number of engines with a wide variation of available cycles which have to reflect emissions in various traffic situations.

Much less expensive method was developed at the Technical University of Graz. This is a semi-empirical method which is based on using as input for the emission factors model, the average speed together with some vehicles and engines parameters including the emissions and fuel consumption from the ECE R49 standard 13-mode test with adapted weighting factors (AWF), [4,6]. Among other works with this subject can be mentioned the TNO simplified model for the calculation of fuel consumption and emissions of heavy duty vehicles and the model developed by the University of Melbourne which is able to transfer chassis dynamometers results to real driving conditions by way of an engine mapping model that was deduced from chassis dynamometers tests.

1. Objectives

The objective of this work is to describe the methodology which was used to estimate emission factors for buses in Israel.

2. Methodology

Due to equipment limitations, we are forced to use the method, which was developed in the Technical University of Graz. This method is based on using the results of type approval emission measurements (emission, power and fuel consumption) according to the ECE R49 standard 13-mode cycle, with addition of adapted weighting factors (AWF) which are obtained for real driving conditions in Israel [3,4,6].
The buses emission factors were estimated as follows:

Urban buses
The driving of an urban bus can be classified as "stop and go" with the engine operation in the following modes: acceleration deceleration, constant speed and idle. To obtain the real-world driving patterns of the buses was necessary to measure the relevant parameters during the realistic driving condition on representative selected routes. The method includes the following steps, [3]:
- selection of the representative routes, which was carried out together with the Bus Company traffic specialists.
- selection of the buses involved in the experimental part of this work.
- instrumentation of the selected buses with the measuring equipment and data logger to obtain the following parameters: bus speed, bus engine's speed, position of the fuel injection pump (FIP) lever.
- analysis of the experimental data for each route and processing these results with calculation of the relative time of engine running at various regimes (engine speed and position of fuel injection pump lever – which is proportional to the engine torque – enable to define engine operation mode).
- laboratory experiments or calculus to establish the relation between the position of fuel injection pump lever and the engine's torque.
- calculation of the adapted weighting factors (AWF), which show the relative contribution of each mode from the ECE R49 13-mode cycle during the real driving of the bus.
- calculation of the specific emission factors per 1 Kg of burned fuel for bus engine of different generations according to test results from the type approval certificate (in conformity with the ECE R49 standard).

The block-scheme of the measurement system is shown in Figure 1.
As it is explained in [3,4], when the AWF-method is applied, the total emission is estimated by weighting the individual emissions at the mode points of the type approval test according to their frequency of use. During driving, the engine delivers power to the bus at load points in the whole operating field. By distributing these theoretically infinite number of load points over the limited number of mode points the AWF are obtained.

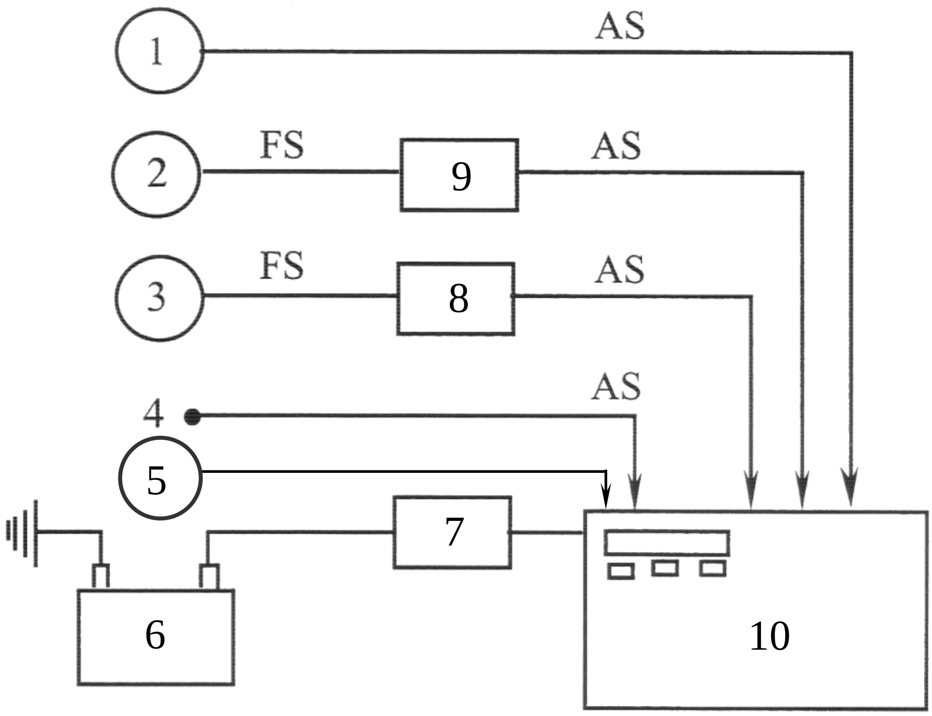

Fig. 1: Block-scheme of the measurement system.
1 – angle measurement sensor for the FIP lever position; 2 – engine revolutions measure device; 3 – bus speed measure device; 4 – thermocouple for ambient temperature measure; 5 – AC operation (on,off) signal; 6 - bus baterry; 7 – voltage transformator DC 24/12 V; 8,9 – frequency analogic transformator F/A; 10 – Data logger; AS, FS – analogic signal, frequency signal.

Pollutants measurements results for ECE R-49 modes were obtained from the buses manufacturer. The following equations were for the mentioned above calculations of emission factors:

$$B_e = \frac{\sum_{i=1}^{11} (B_{ei} \times AWF_i)}{\sum_{i=1}^{11} (P_i \times AWF_i)}$$

$$B_f = \frac{\sum_{i=1}^{11} (B_{fi} \times AWF_i)}{\sum_{i=1}^{11} (P_i \times AWF_i)}$$

Where:

B_e - total emission of one of the pollution components (NOx, CO, HC or PM), which was calculated using the ECE R49 13-mode cycle data with the help of the adapted weighting factors for the realistic bus driving conditions in Israel, g/kWh.
i - order number for each, from the 13 cycle modes.
B_f - fuel consumption which was calculated in the same way.
B_{ei} - emission for of one of the components for the cycle mode i, g/h.
B_{fi} - fuel consumption for cycle mode i.
P_i - engine power for mode i of the cycle, kW.
AWF_i - adapted weighting factor for the cycle mode i.

The specific emission (b_e), g/kg_{fuel} of each pollutant is given by the equation:

$$b_e = \frac{B_e}{B_f} = \frac{\sum_{i=1}^{11} (B_{ei} \times AWF_i)}{\sum_{i=1}^{11} (B_{fi} \times AWF_i)}$$

The emission factor for buses from different generations can be calculated with the equation.

$$EF = \overline{b}_e \times \overline{b}_f \;,\quad g/Km$$

Where

$\overline{b}_e$ - mean value of the specific emission for different buses generations, g/Kg fuel
$\overline{b}_f$ - mean value of the specific fuel consumption for different buses generation Kg fuel/Km

Interurban buses

For the Israeli conditions it was supposed that the covered distance for an interurban bus can be divided as follows:
- 74% at constant speed (high-way [hW] conditions)
- 26% at urban conditions

and the emission factor can be calculated with the equation:

$$EF_{iu} = 0.74\,EF_{hW} + 0.26\,EF_u$$

where EF_{hW} and EF_u are respectively emission factors for bus constant speed and for urban driving conditions expressed in g/Km. These were calculated as a function of the bus power consumption, P_{hW} for driving the bus at constant speed (V = const.) as follows:

The engine torque is calculated using the equation

$$T = 9740\frac{P_{hW}}{n} \;,\quad N \cdot m$$

Where n is the engine speed [rpm] for V = const.

For the steady state engine operation.the hourly fuel consumption $(B_{f,hW}, Kg/h]$ and the hourly pollutants emissions $(B_{e,hW}, Kg/h]$ were calculated [4]. The emission factor for V=const is given by the equation:

$$EF_{hW} = B_{ehW} / V_{hW} ;\ g/Km$$

Conclusions

The methodology presented in this work offers the possibility to estimate the emission factors for buses (and more generally for heavy-duty vehicles) based on the results of type approval emission measurements according to the ECE R49 (or new ESC) standard 13-mode cycle, with addition of AWF , which are obtained for real world driving conditions in Israel.
The results obtained for the emission factors are appropriate to the realistic values but it is necessary to underline that this methodology is laborious and does not taking into account transient effects.

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