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Abstract
Ten European laboratories worked together to study the influence of a lot of parameters of the measurement of light vehicle emission factors on vehicle bench, in order to improve the accuracy, reliability and representativeness of emission factors: driving patterns (driving cycles, gear choice behaviour, driver and cycle following), vehicle related parameters (technical characteristics of the vehicle, emission stability, emission degradation, fuel properties, vehicle cooling and preconditioning), vehicle sampling (method, sample size), and laboratory related parameters (ambient temperature and humidity, dynamometer setting, dilution ratio, heated line sampling temperature, PM filter preconditioning, response time, dilution air). The results are based on literature synthesis, on about 2700 specific tests with 183 vehicles and on the reprocessing of more than 900 tests. These tests concern the regulated atmospheric pollutants and pre-Euro to Euro 4 vehicles. We did not find any influence of 7 parameters, and find only a qualitative influence for 7 other parameters. 6 parameters have a clear and quantifiable influence and 5 among them allow us to design correction factors to normalise emission measurements: gearshift strategy, vehicle mileage, ambient temperature and humidity, dilution ratio. The sixth influencing parameter is the driving cycle, sometimes more significant than the fuel or the emission standard. The results allow us to design recommendations or guidelines for the emission factor measurement method.
Keys-words: emission factor, light vehicle, model, inventory, regulated pollutant, guidelines, measurement conditions, method.

Introduction

Calculation of emissions has therefore gained institutional importance in the European Community, particularly with the development of the Café (EC, 2005a) and ECCP (EC, 2005b) programmes. Reliable and credible emission estimates are a central prerequisite, but comparisons of the results from emission models such as Copert (Ntziachristos & Samaras, 2000), Foremove (Samaras et ali, 1993), Tremove (De Ceuster et ali, 2005), Rains (Amann et ali, 2004), Handbook (Keller,

2004) and national models have shown substantial differences. This causes doubts about the credibility of the underlying data and methodologies and might mislead the political discussions.

The European MEET (Methodologies for Estimating air pollutant Emissions from Transport) project (Hickman et ali, 1999), the COST 319 action (Joumard, 1999) and other research programmes raised a main question in relation to passenger car emissions, summarised as follows: large differences in measured emission levels occurred between the different laboratories in Europe; these differences appeared to be more pronounced for more recent (at this time) vehicle technologies (i.e. Euro 1), irrespectively of the way the emissions modelling is conducted (i.e. average speed dependency approach, traffic situation approach).

In order to be able to produce accurate emission factors for current and near-future technology, taking into consideration the aforementioned observations for modern car categories, a two-fold strategy is proposed in the present study: i) investigating and reducing the measurement differences between laboratories, ii) investigating, understanding and modelling the emission differences among comparable vehicles. The first aim is to study the sensitivity of pollutant emissions to the key parameters. The second aim is to develop methods that allow the harmonisation of any European emission measurements.

This study, detailed in Joumard et ali (2006) is a part of the Artemis project "Assessment and Reliability of Transport Emission Models and Inventory Systems", whose purpose is to arrive at a harmonised methodology and to develop a software that calculates emissions of any transport mode, at local, national and international level.

1 - Methodology

The influence of all the potential parameters on the exhaust emission level and accuracy is studied first with a literature review and then by laboratory tests on vehicles. Four types of parameters of the measurement conditions are studied:
- Driving patterns: driving cycles, gear choice behaviour, influence of the driver and cycle following
- Vehicle related parameters: technical characteristics of the vehicle**s**, short term emission stability, long term emission degradation (mileage), fuel properties, vehicle cooling, vehicle preconditioning
- Vehicle sampling method: method of vehicle sampling, number of vehicles
- Laboratory related parameters: ambient temperature, ambient humidity, dynamometer setting, dilution ratio, heated line sampling temperature, PM filter preconditioning, response time, instantaneous vs. bag value, dilution air conditions

Parallel to the study of the impact of different parameters on emissions, we compare the roller test bench laboratories to each other by performing a round robin test with reference gases on the common fuels basis.

A specific test programme was built-up for each parameter studied, excepted the vehicle running conditions and the method of vehicle sampling, where only literature review or inquiries were performed. Emissions of CO, CO_2, HC, NOx, and PM are considered. Although a wide variety of driving cycles were tested for the whole study (65 cycles), most of them have been used either to look at the influence of the driving patterns, or when reprocessing existing data (case of the minimum size of a vehicle sample). For the influence of the vehicle and laboratory related parameters, the 3 Artemis driving cycles (André, 2004) have been generally tested with hot start, but in a few cases without the rural or motorway cycles. In many cases cold and/or hot NEDC have been tested in addition. All the tested driving cycles are described and analysed by (André et ali, 2006a; André and Rapone, 2006). The tests have been spred out in the different partner laboratories.

Globally 2753 tests are carried out (1 test = 1vehicle x 1 driving cycle), i.e. 537 tests to look at the

influence of the driving patterns (48 vehicles), 1334 tests to look at the influence of the vehicle parameters (70 vehicles), 672 tests to look at the influence of the laboratory related parameters (64 vehicles), and 210 tests are part of the round robin test conducted within 9 laboratories with a petrol passenger car. In addition at least 910 tests (81 vehicles) from the European Artemis data base but not carried out within the project are processed in order to look at the influence of the driver and mainly the vehicle sample size.

2 - Results

According to the outputs of the above studies and in the conditions of the tests, some parameters have no influence on the emission measurements, or have a qualitative, or a quantitative influence.

Not influencing parameters

We did not find any statistically significant influence on emission measurement for some parameters. It does not mean that these parameters have no influence on the emission measurements, but only that we cannot prove any influence, taking into account the small data sample or the contradictory results.

Vehicle related parameters
- Short term emission stability or driving cycle repetition
- Inspection-maintenance
- Fuel properties. The results confirm the influence of fuel on exhaust emissions, but in spite of observing significant differences, especially for PM emissions with diesel vehicle, it was not possible to propose an explanation based on the today knowledge of fuel effect
- Vehicle cooling. The open and close bonnet, the height of a small blower have no influence on the emissions measured. The cooling power, i.e. the flow of the cooling air, hasn't a clear influence on the measured emissions

Laboratory related parameters
- Heated line temperature, because the observed emission change contradicts what is expected from the physico-chemical properties of the diluted emissions
- PM filter conditions
- Dilution air condition

Parameters with qualitative influence

Some parameters have a qualitative influence. Therefore recommendations are made concerning these parameters:

Driving patterns
- The driver can be a human driver or a robot. Only the CO_2 emission was significantly higher by +4 % with human driver than with a robot driver, but the difference cannot be explained by the driving characteristics.

Vehicle related parameters
- The vehicle classification, through the type approval category (Euro 1 to 4) and the fuel, has a clear influence on the emissions, together with the engine capacity in some cases. But no correlation between emission behaviour and emission control technologies were found as long as the cars belong to the same type approval category. Therefore the additional introduction of technological characteristics won't improve the accuracy of emission data bases of conventional cars up to Euro 4.
- The vehicle preconditioning conditions have an influence in some cases, but very few for modern close loop vehicles. A 10 minute cycle at a constant speed of 80 km/h can be considered as the most suitable preconditioning cycle. It resulted in the lowest emission levels and the lowest standard deviation for the majority of the measurements.

Vehicle sampling method
- The sample characteristics influence the emission levels: the vehicle classes given above, but also the size and engine power at the maximum power of the vehicle, which influence a lot the CO_2 emission and fuel consumption.
- Minimum size of vehicle sample. Usually 10 to 15 vehicles are required for all the pollutants, in order to build-up an emission model which is representative of an average vehicle behaviour. Below these prescribed numbers, the weight of the individual behaviour of some vehicles is too significant to obtain a mean, which is representative of an average behaviour.

Laboratory related parameters
- The dynamometer setting has a clear influence on all emissions, but significantly only on CO_2 and fuel consumption, and on NOx for diesel vehicles. It cannot be excluded, however, that altered settings might affect these other pollutants too.
- Response time including instantaneous versus bag value. The measured instantaneous emission level must be corrected using specific functions, before building an instantaneous emission model (Zallinger et ali, 2005).

Influencing parameters

6 parameters have a clear and statistically significant influence on the emissions measured. The influence of 5 parameters can be quantified and quantitative correction factors are available in order to standardise emission measurements for the parameters gearshift strategy, vehicle mileage, ambient air temperature, ambient air humidity and exhaust gas dilution ratio.

Driving patterns
- Driving cycle. The variation induced by the driving type or cycle was more significant than the variation induced by the fuel type (for HC, CO_2), or by the emission standard (NOx, CO_2), or even between the vehicles (CO_2), with quite contrasted behaviour between diesel (rather sensitive to speed and stop parameters) and petrol cars (rather sensitive to accelerations). However, it was not possible to design a satisfying correction function, but an harmonisation approach was then developed, based on the similarities between cycles from a kinematic point of view (André and Rapone, 2006).
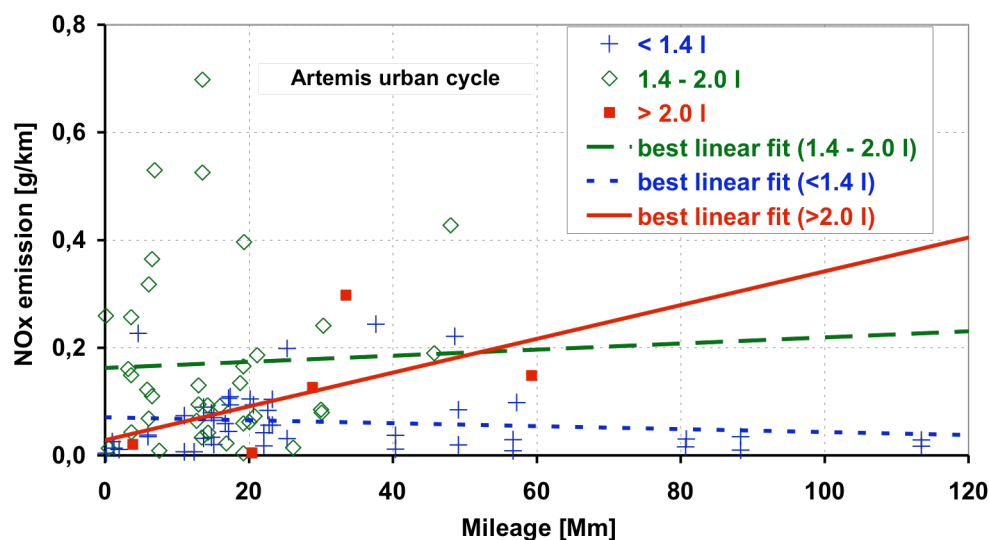

Figure 1:   NO$_x$ degradation in urban driving behaviour for petrol vehicles.

- Gearshift strategy. It is possible to classify the gearshift strategies according to their CO_2 emission (the only pollutant always influenced by the strategy). The most polluting strategy is the gear change at given engine speeds whatever the cycle. The less polluting strategy seems to be the gear change at given vehicle speeds (defined in the NEDC cycle). The ratio between these two strategies is around 15 %. For urban cycle, the strategy depending on the vehicle power-to-

mass ratio and on the 3rd gear ratio (part of the Artemis cycles) pollutes as the gear change at given vehicle speeds. For rural cycle, the Artemis strategy pollutes less than given engine speed strategy (9 %) but more than the given vehicle speed strategy (6 %).

Vehicle related parameters
- The mileage has no influence on the CO_2 emission neither on the emissions of diesel vehicles, but increases a lot CO, HC and NOx emissions of petrol cars: between 0 and 100 000 km, these emissions increase by a factor 3.6 in average for Euro 1 and 2 vehicles, and by 15 % for Euro 3 and 4 vehicles (see an example Figure 1).
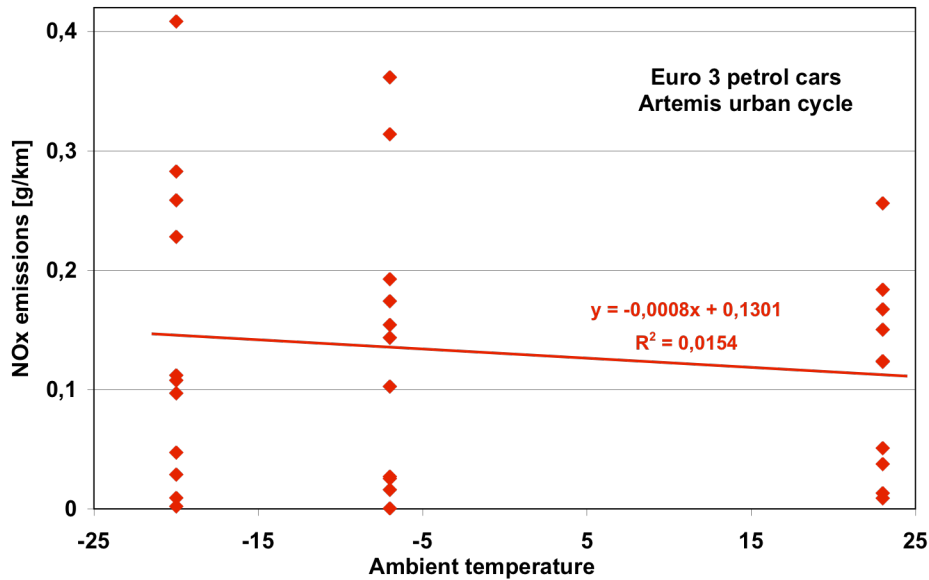

Figure 2:   Influence of the ambient temperature [°C] on the NOx emissions [g/km] of Euro 3 petrol cars over the Artemis urban driving cycle.
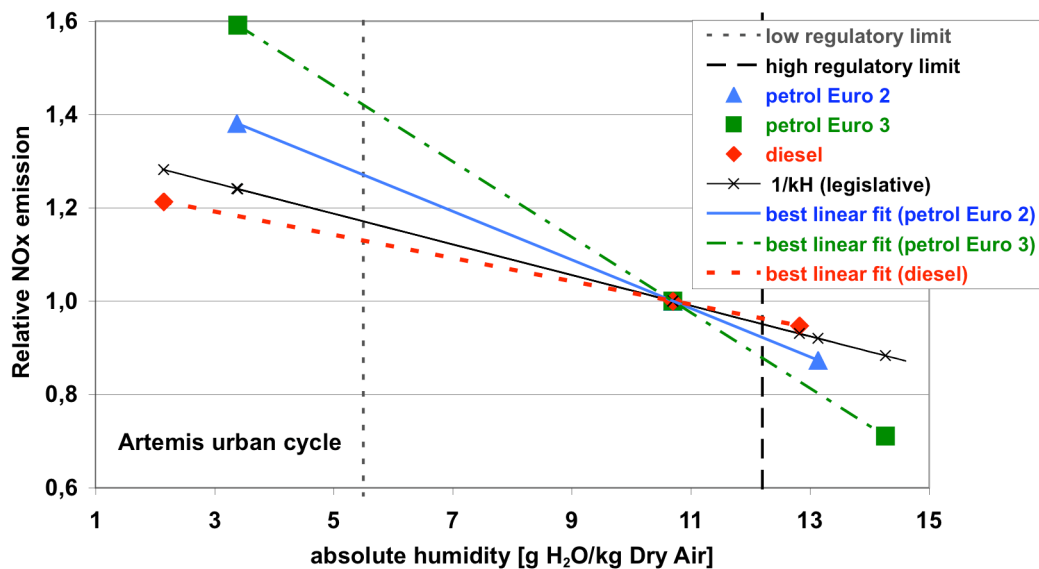

Figure 3:   Linear models of (uncorrected) NOx emissions measured in Artemis urban driving cycle, fitted in average values for high, medium and low humidity, and correction factor according to legislative test protocol (as 1/kH).

Laboratory related parameters
- Ambient air temperature. The hot emissions decrease with increasing temperature for petrol cars but mainly for diesel ones. Between 10 and 20°C, the CO and HC emissions varies by 15-20 %, the NOx and CO_2 emissions by 2 %, and PM is constant. The influence of the ambient

temperature is usually a linear function (see an example Figure 2) and sometimes an exponential one.

- The influence of the ambient humidity exists only for NOx and for some vehicle classes. It is a linear function. An increase in ambient humidity lowers the NOx emissions, which is also the expected general trend according to the humidity correction established in legislative testing (EEC, 1991). Figure 3 shows that in urban test cycle the standard correction is nearly valid for diesel cars with less than 5 % deviation from the now-established model. However, both groups of petrol cars would need much stronger correction, as the relative change over the allowed humidity range is about 35 % for the Euro 2 to and over 55 % for the Euro 3 test fleet, and the normative factor corrects only by some 20 % within the same range of humidity.
- Exhaust gas dilution ratio. A higher dilution ratio increases only the diesel PM emission measurement.

Round robin test

The best accuracy (i.e. lowest spread in results) was encountered for CO_2, where the average coefficient of variation was around 5 %. This latter is around 40 % for CO, below 40 % for NOx, and around 60 % for HC. When comparing these variations to those values calculated on the basis of the repeated tests at the begin and at the end of the whole round robin test in a same laboratory, we see that the overall variability recorded for CO in the round robin test was roughly at the same order of magnitude than the "basic" repeatability combining the repeatability of the laboratory and fluctuations in the car performance. However, with HC the overall spread of results over the whole round robin test was higher, suggesting that some external factors, like the change in fuel quality, affected and lowered the repeatability. In terms of NOx, the overall round robin test variability was also somewhat higher than the basic value obtained from one laboratory alone, but we made no speculations over the probable reasons to this.

3 - Guidelines

The knowledge of the sensitivity of vehicle pollutant emissions to the key parameters identified above allows us to design a best practice for measuring emissions of the European passenger car traffic. These guidelines can be displayed into four directions: Which cars to measure? In which conditions to test the cars? How to sample and analyse the pollutants? How to manage the data?

Vehicle sampling

We recommend to choose as far as possible a vehicle sample with similar distributions than the in-use fleet of the fuels, emission standard, vehicle size, maximum engine power. At least the means or medians of the cubic capacity, maximum power and mileage should be similar.

The variability between vehicles is also identified as a significant and preponderant factor, together with the emitter status (high/ or normal emitter). It is not possible to know a priori the emitter status before measuring, but the high variability between vehicles of a same category obliges to choose the cars randomly within a category and to sample a minimum number of vehicles. The minimum sample size per vehicle category, with the aim to calculate only an emission average per vehicle category, seems to be not less than 10 vehicles. We recommend to carry out only a limited number of repetition tests on these cars instead of taking a smaller sample tested many times. The vehicles to test should be chosen the most possible randomly in a list created by an official body as government, because it will give results closest to the fleet representativeness. If an official list cannot be obtained, the list created in laboratories should be completed by vehicles owners, which the profession is not in relation with the pollution, like the laboratory staff.

Usage conditions of the vehicles

The vehicle conditions in the measuring laboratory should correspond to the range of traffic conditions observed in Europe: it concerns not only the driving patterns, but also the environmental

conditions, the vehicle load, the fuel used...

Driving cycle: It is highly recommended to test the passenger cars with real-world driving cycles. A lot of such driving cycles are available in Europe. We recommend the so-called Artemis driving cycles now widely used in Europe to measure passenger cars emissions (André, 2004), or vehicle-specific driving cycles (André et ali, 2006b) to measure actual European pollutant emission factors.

Gearshift strategy : The gearshift strategy depending on the vehicle power-to-mass ratio and on the 3rd gear ratio, i.e. foreseen in the Artemis and vehicle-adapted driving cycles, seems to be the most appropriate. But the strategy impact remains nevertheless relatively low as soon as realistic patterns are selected.

Vehicle preconditioning : We propose as preconditioning cycle a constant speed cycle with a reasonable vehicle speed level, especially for petrol cars: a 10 minutes cycle at a constant speed of 80 km/h for instance.

Driver: The robot does not give more stable emissions and some driving cycles are too aggressive for it. Therefore it is no reason to prefer robot than a human driver. We recommend that a cycle following should be in the tolerance band (± 2 km/h and ± 1 s) for more than 99% of time and with a driven distance within 1 % to the reference distance. A test is accepted with remark if it fails these values due to insufficient power, wheel slip, difficult gear box, in NEDC if deceleration is steeper than reference or if the engine stalls or does not activate immediately at test start. In all other cases a test should be rejected.

Fuel characteristics: Both diesel and petrol fuels influence a lot the emissions, but not CO_2. Therefore it is recommended to use common fuels rather than laboratory fuels.

Ambient air temperature and humidity: It is recommended to measure the emissions close to the average ambient temperature and humidity rather than at "standard" one when this one is far from the reality.

Vehicle cooling: We recommend to use a high power cooling system, in order to reproduce as far as possible the real-world cooling.

Dynamometer setting: Although only few effects were found significant, the chassis dynamometer settings should lead to a load applied to the driving wheels of a vehicle that is equivalent to the load experienced on the road at all speeds and accelerations. For the testing to be performed for the determination of real world emission factors, it is therefore primarily recommended to use road load information derived from the coast down method performed by the laboratory, and an inertia setting as close to the actual on road inertia as possible, which is also determined by the laboratory.

Conclusion

The study was designed to look at the influence of a lot of parameters of the measurement of light vehicle emission factors: driving patterns, vehicle related parameters, vehicle sampling method, and laboratory related parameters.

In the conditions of the tests, we did not find any influence of some parameters. For some other parameters we showed a qualitative influence we are not able to quantify. Finally some parameters have a clear and quantifiable influence and can be used to normalise emission measurements when the level of these parameters during the experiment is known, by using correction factors: gearshift strategy, vehicle mileage, ambient air temperature and humidity, exhaust gas dilution ratio. The results allow us to design recommendations or guidelines for the real-world emission factor measurement method. All these outputs have been used to design the Artemis emission inventorying tools for light vehicles, on a better basis than the previous European models.

The outputs of this study are nevertheless not fully positive, mainly because of the too small number of tests performed to look at the influence of some parameters, which did not allows us to

find any significant influence. Some parameters could therefore be studied again.

Acknowledgments

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