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To cite this version:
Robert Joumard. Do emission standards meet environment challenge?. The motor car and the environment, the clean air act: the challenge of the nineties, ISATA, May 1991, Florence, Italy. pp.8. hal-01254281

HAL Id: hal-01254281
https://hal.archives-ouvertes.fr/hal-01254281
Submitted on 12 Jan 2016

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DO EMISSION STANDARDS MEET ENVIRONMENT CHALLENGE?

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Abstract
The representativity of the European driving cycles (ECE15 and EUDC) was analysed with respect to speed and acceleration from the results obtained in different instrumented studies carried out in Europe on about a hundred private cars. Then for 70 gas or diesel engined in-use vehicles, emission levels determined according to the applicable standard were compared to CO, HC and NOx emission values measured according to the standard or on in-use vehicles. Thus, the standard values are often exceeded, in particular for CO and HC emissions. In addition it should be noted that American, Japanese and European emission standard are far behind the current environmental problems relating to air pollution. The relative significance of the different environment elements (population health, forest decline, greenhouse effect, ...) changes very rapidly, as well as the number of related pollutants. A single standard taking into account a weighted set of pollutants could better and more obviously meet the environment challenge and could provide car manufacturers with a larger choice of "clean" technologies.

To address the issue of vehicle pollution all industrialized countries endeavoured - some of them earlier than others - to draw up and implement regulations to reduce the significant pollution phenomenon and to protect the environment and public health. Environment and emission standards are aimed at reducing the effects of some pollutant or other on the environment and in particular on man. The process of standard drawing up is very complex and takes into account three types of rationality (Georgiades and al., 1988):

- scientific rationality aimed at protecting the whole population, and if required the whole environment, from pollutant effects;

- economic or industrial rationality aimed at protecting involved industries or furthering their development;

- political rationality which is the expression of the social awareness.
The standard drawn up is always the result of a compromise or arbitration; the great variety of interests at stake, the great variety of environment issues and even more how they are perceived in some country or other, as well as the advantages or problems of national industries can explain the great variety of standards. For example in Europe the standards firstly met health requirements (CO, HC), then were a response to the forest decline (NOx). In the United States, to health concerns were added the visibility problem (particulates) and then the photochemical smog (HC, NOx).

Under present conditions, do the different emissions standards meet the requirements of the three rationality types hereabove mentionned? In other words, do they actually allow ensuring that all the air pollution phenomena, as described by scientists and deemed significant by the population, are correctly addressed, and that industrial requirements, and in particular as related to vehicle industry, are complied with at best with no more or less unwitting perverse effects?

The representativity of emission standards in terms of speed, and for the European standard in terms of emission, will be assessed. Then, due to the significant development of environment challenges the very building of the standards will be discussed.

1 - Representativity of emission standards

Speed representativity

The speed cycles used significantly vary according to the standard applied. For each case studied, these cycles are deemed representative of actual speed cycles: Americans used actual cycles that have been only slightly simplified and therefore are very realistic. Japanese or European cycles were reconstituted cycles that included only constant acceleration periods, so that transient phenomena were not fully represented. Speeds and accelerations are considered for the different cycles and are classified according to real driving conditions, e.g. as recorded in France (Maurin and Crauser, 1990). Thus, four main driving cycles can be observed: slow urban, free flow urban, road and motorway driving cycles, which account for 3, 38, 50 and 9% of the distances covered by light vehicles in France respectively. European and Japanese cycles mainly consider free flow urban driving conditions while American cycles mainly take into account road driving conditions; i.e slow urban or fast motorway driving conditions are not addressed. Nevertheless, it is assessed that very high levels of CO and even of hydrocarbons are emitted at low speeds, while NOx are emitted at high speeds.

Standards also specify the gear box ratios to be used. The gear box ratios are set for all the vehicles in the ECE 15 cycle, while the Japanese and American cycles differentiate the 4- and 5- geared vehicles. The actual spacing of the gear box ratios which varies from one model to another is never taken into account and this leads to the use of test engine speeds that do not correspond to actual driving conditions, as the vehicle speed, gear box ratio and engine speed are related in an univoval manner. Therefore, for vehicles with the highest gear box ratios, NOx emissions are underestimated as the vehicles are tested with engines running at lower speeds than those recorded under actual driving conditions.

Measurements - simultaneously carried out using the same methodology in France, Great Britain and Germany on 60 private cars driven by their usual driver(s) during a one month period (André and al., 1991) - showed that there is a great range of speeds and especially accelerations commonly used by the drivers. The driving cycles used for standard drawing up, and in particular for the European standard, are not representative of such a variety.
**Emission-related representativity**

The ECE 15 standard representativity has been measured in terms of pollutant emissions over a representative sample of French passenger vehicles of the end of 1988 (Joumard and al., 1990). Two complementary issues were addressed to measure representativity: do the emission level measured according to the standard correspond to the emission level measured under actual driving conditions and do the measurement method used (ECE 15) enable to accurately calculate the evolution of vehicle emissions over several years?

Pollutant emissions were measured under actual driving conditions using 10 driving cycles (fig.1), representing actual French driving conditions (Joumard and al., 1987; Maurin and Crauser, 1990). To assess the representativity of the standardized ECE 15 and extra-urban (EUDC) driving cycles, emission levels measured for these cycles were compared to the assessed level of the emission curve on Inrets representative cycles using the same average speed, identical vehicles, i.e. as-received vehicles under hot start conditions. It can be noted (table 1) that for gas-engined vehicles, standardized cycles underestimate emissions by about 25% for all the pollutants studied, with nevertheless some discrepancies for some of them: e.g. the extra-urban driving cycle underestimates CO and HC emissions by about 50%.

For diesel-engined vehicles, the ECE15 cycle underestimates emissions by 15% in average, with nevertheless a good agreement for CO emissions. In general, no problem is to be observed with extra-urban driving cycle for these vehicles, a slight overestimation can even be observed, up to 30% for particulates.

As regards emissions, standardized cycles are globally located half way between stabilized speeds and representative cycles, which corresponds to actual speeds.
Table 1: Approximate relative position of emissions in standardized fully warmed-up cycles as compared to representative Inrets hot cycles using the same average speed with as-received vehicles.

Underestimation of the results for the ECE 15 cycle is a function of the pollutant studied and mainly of the fuel type used. The ECE 15 cycle, as the EUDC for gas-engined vehicles only, gives an erroneous and inaccurate emission representation.

Compliance with the standard

The ratio evolution between emissions actually measured during testing and the emission limits for each vehicle during out-plant testing has been studied.

At first, the deviations between vehicle specifications and the standard to be applied were studied. The CO, HC, NOx or HC+NOx levels of the European standard were compared to the values of the same pollutants measured on as-received or tuned vehicles for the ECE 15 cycle.

For gas-engined vehicles, figure 2 shows that CO emissions - CO is the only pollutant which has been separately regulated since the implementation of the European standard - for as-received vehicles are higher than those specified in the standard, by 70 to 120%. Total HC emission is also significantly higher than allowed in the standard, by 30 to 190%. On the other hand, NOx or HC+NOx emissions are in average significantly lower than those allowed.

The amendment to the standard (15-01 to 04) has no significant influence on the results. The situation is likely to be "standardized" for the most recent vehicles, either because they were less old, or they better complied with the standard when manufactured.

The average values obtained include a great variety of situations. Indeed a number of vehicles (gas-engined vehicles) meets the standard requirements (see distributions fig.3):

- for CO: 27% of the vehicles complied with the standard requirements before tuning (and 35% after); a significant number of the values recorded exceeded by a factor 3 the standard values, by 1.92 in average (1.63 after tuning);

- for HC: 60% of the vehicles complied with the standard requirements before tuning (59% after), the average was 67% above the standard value (and 41% after tuning);

- for NOx: 94% of the vehicles studied (1502 and 03 standard) complied with the standard requirements (96% after tuning), the average value was 54% (58% after tuning);
Figure 2: Average of the ratio emission measured in cold ECE 15 cycle/standard series emission limit, according to the pollutant studied and the successive amendments to ECE 15 standard.

Figure 3: Emission distributions for cold ECE 15 cycles in accord with the ECE 15 standard relating to gasoline engined vehicles.

- for HC + NOx (1504 amendment only): 78% of the vehicles complied with the standard before and after tuning and the average decreased from 81% to 76% of the standard value.

Therefore it can be noted that vehicle tuning slightly improves the situation, even if it slightly increases NOx emissions. This improvement is not systematic: e.g. tuning of older vehicles (amendments 1500-01) significantly increases HC emissions and therefore the values obtained are very far from the standard requirements (see fig.2).
Nevertheless our measurement conditions for the cold ECE15 cycle are not exactly those specified in the standard: the test temperature is the outside ambient temperature. Thus ambient temperature (and therefore engine temperature at start) ranges from 20 to 30°C only in 3 cases out of 48 studied for the cold ECE 15 cycles with tuned and as-received vehicles (it is lower in all the other cases). This could explain the significant number of recorded values exceeding the standard values. But in fact no significant and systematic discrepancy can be noted according to ambient temperatures:

- for CO, the percentage of values exceeding the standard values does not depend on ambient temperature for as-received vehicles, and is even lower in average for temperature under 20°C with tuned vehicles;

- for HC, the percentage of exceeding values is lower for temperatures under 20°C (in average by 1.7 the standard value under 20°C, and 1.30 above) for as-received vehicles; after tuning, the percentage of exceeding values increases with temperature: by 1.24 and 2.42 times the standard value under and above 20°C.

For diesel engined vehicles whose emissions have been regulated from the implementation of the last amendment only (1504), the situation is excellent: all the vehicles highly comply with the CO and HC + NOx limit values, in average by 6% and 18% of the standard respectively (and by 5 and 16% after tuning).

2 - Rapid evolution of the environment challenges

The air pollution issue is multi-sided as many primary pollutants are to be taken into account and as it relates to varying and evolving phenomena: effects on human health which historically justified the first studies and the drawing up of the first standards, perceived pollution (visible pollution, fumes, odors, soiling) which is essentially a nuisance and identified by the population to the whole air pollution (even if the experts are not much concerned with it in Europe), photochemical pollution which is becoming a worldwide concern after having been dealt with in the USA, the forest decline which is mainly a European concern and finally the greenhouse effect, the only type of air pollution which led to the rallying of the highest political authorities, and maybe soon new polluting effects on our environment ...

Current emission standards do not comply with the multi-sided and evolutive character of air pollution: for example, many pollutants which have significant effects on health are not taken into account (PAH for example), the greenhouse effect or even photochemical pollution are not considered as such, i.e as the result of the presence of a number of pollutants, each of which specifically contributes to these phenomena. Only some pollutants are taken into account but their emission limit is not related to their effects on the environment.

Nevertheless, increasing the number of pollutants to be considered can lead to significant discrepancies in the technological and therefore economic fields by making inadequate a given technology: such was the case in the United States where stringent standards on diesel particulates stopped the development of this technology while in other respect, diesel engines are far less polluting than gas engines (without catalyst): the comparison of 50 gas-engined and 20 diesel-engined vehicle emissions (Joumard and al., 1990) showed that diesel engine CO emissions were 30 times lower than gas engine emissions, and total HC emissions 15 times lower and NOx emissions 2-3 times lower (see table 2). In the same way, the consideration of 3 pollutants, CO, HC and NOx naturally led to the adoption of a three-way catalyst which precluded the use of lean burn engine, even if it proved to be interesting as regards CO2 emissions which no standard has taken into consideration.
Table 2: average of gasoline engined/diesel engined vehicle emission ratios for Inrets cycles with as-received vehicles using cold and hot starts.

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>CO₂</th>
<th>HC</th>
<th>NOₓ</th>
<th>PAH</th>
<th>fuel cons.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot</td>
<td>28.5</td>
<td>0.86</td>
<td>13.4</td>
<td>3.2</td>
<td>1.21</td>
<td>1.09</td>
</tr>
<tr>
<td>Cold</td>
<td>33.7</td>
<td>0.96</td>
<td>24.5</td>
<td>0.60</td>
<td>20.6</td>
<td>1.52</td>
</tr>
</tbody>
</table>

The multiplicity of concerns, and therefore the great number of pollutant emissions to be reduced, the requirement of providing the most open as possible technological choice to meet all the environment challenges and the related energy challenge due to the greenhouse effect, led us to consider the need of a more global and flexible designing of a new standard.

3 - Towards a global emission standard?

The aim is to define a standard which addresses all the air pollution issues, each issue taking into account a limited number of more or less active primary pollutants. In addition, this standard should be evolutive and be applied to any type of vehicle without any discrimination.

First, the concept of "air pollution" could be define as the sum of different types of pollution (health effects, perceived pollution, greenhouse effect, etc...) weighted as a function of their significance according to the scientific community and even more the population through its representatives. It could be considered that health effects should be weighted by a factor 2, perceived pollution by a factor 1 and greenhouse effects by a factor 1.5.

Then, each pollution type could be express as the sum of a number of pollutants, each of them being weighted according to its contribution to pollution, as experts can assess it at a given time according to their current knowledge. Thus the greenhouse effect is due to CO₂, HC (22 times more active), CO (5 times more active) and NOₓ (3 times more active). The standard could be written:

\[
\text{standard} = \frac{\beta_1 \cdot \text{Pollution}_1 + \beta_2 \cdot \text{Pollution}_2 + \beta_3 \cdot \text{Pollution}_3 + \ldots}{\beta_1 + \beta_2 + \beta_3 + \ldots}
\]

Where

\[
\text{Pollution}_i = \frac{\alpha_{i1} \cdot \text{pollutant}_1 \cdot \text{emission} + \alpha_{i2} \cdot \text{pollutant}_2 \cdot \text{emis} + \ldots}{\alpha_{i1} \cdot \text{emis}_1 + \alpha_{i2} \cdot \text{emis}_2 + \ldots}
\]

The pollution, "standard" must be normed according to an average value for the whole traffic type considered at the initial period (e.g. passenger cars). Therefore for the initial period, a global emission level (GEL) representing all the air pollution phenomena and the average actual traffic emissions can be determined and normed by definition to the 100 value of initial period:

\[
\text{GEL} = 100 \cdot \frac{\sum_i \beta_i \frac{\sum_j \alpha_{ij} e_j}{\sum_j \alpha_{ij} e_j}}{\sum_i \beta_i}
\]

where \( e_j \) is the \( j \) pollutant emission level (in g/km).

This yields a Global Emission Level (GEL) representing the weighted sum of all pollutants emission levels, according to the weighting factors hereabove defined.
A more stringent standard - definitely a politico-economic choice - by n% will lead to the reduction of the global emission level by n% and thus, under equal traffic conditions, to an actual n% improvement of the air environment. Car manufacturers will be required to comply with the new global standard, but will be given the possibility of selecting by themselves appropriate technologies, even through increasing the emission of such pollutant provided that emissions of such other(s) will be reduced. The knowledge development in the environment field can allow the taking into account of new pollutions or new pollutants. A new global emission level should therefore be defined.

Conclusion

Current vehicle pollutant emissions standards are not much representative of the actual use of vehicles from a speed perspective. They are therefore inadequate to represent the actual emission evolution: a more stringent standard may lead to no actual emission evolution as these standards, and in particular the European standard, significantly underestimate the role of very low or very high speeds, high accelerations or decelerations, as well as periods driven at slightly varying speeds.

In addition, the standard definition in terms of pollutants and emission limit for each pollutant is far from representing all the environment concerns which can rapidly change. Such a definition can further a given technology to the detriment of another one on no environment basis, and practically impose a specific technology on manufacturers.

A unique global standard could therefore present some advantages as considered above. The building of such a standard, to be adequate and evolutive, requires the knowledge of traffic average emissions at a given initial period, for all the pollutants considered. In addition it assumes in a simplifying manner that each type of pollution is due to a linear emission combination of different pollutants.

Nevertheless, provided that these requirements are met, the advantage of such an approach is that the standard could be representative on the one hand of the complex environment challenges, and on the other hand could provide motor engineers with a wider room to manoeuvre.

References


