# DEVELOPMENT OF A METHOD TO MEASURE DIESEL SMOKE EMISSION FOR INSPECTION/MAINTENANCE PROGRAMS

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## ABSTRACT

It is well known that even the most severe emission legislation of today for newly developed vehicles cannot provide major reductions in air pollution, without appropriate control of the vehicles technical conditions by Inspection / Maintenance (I/M) programs. The main objective of the work presented here was to develop a method of diesel smoke emission measurement, which will be suitable for use in the framework of I/M procedures and will allow a better enforcement of regulations for various vehicle generations.

In the framework of this work, a comprehensive review of available national and international standards dealing with smoke measurement in road tests was carried out. Benefits and drawbacks of the most widespread free acceleration method were analyzed. Comparison with the constant load method, which is used in Israel today, has been performed. Benefits of on-load measurements over those using free acceleration have been analyzed too.

Analysis of smoke emission measurements in official type approval tests of diesel vehicles of various generations was carried out and demonstrated, as anticipated, the low level of smoke emissions of modern vehicle types. This leads to the conclusion that use of the common limit, as it is applied today, results in rather improper enforcement of the regulations regarding diesel smoke emissions. Since the modern diesel engines are designed to emit less particulates and smoke, the common limit may provoke improper maintenance of vehicles.

The proposed test method is based on smoke emission measurements under full load conditions at constant intermediate engine speed, using a simple chassis dynamometer without inertia masses. Results of the smoke measurements at full load conditions in the official type approval tests according to the 72/306/EEC Directive are used as a basis for definition of the limit value for the I/M test, with different smoke limits for various vehicle types and generations. Thus, automatic updating of emission limits for new vehicle generations will be guaranteed.

The feasibility of the proposed method was checked experimentally on a number of vehicles. Currently, the Israeli Ministry of Transport is working on the preparation of a large-scale pilot, where the new method will be tested in the framework of real annual vehicle tests.

## INTRODUCTION

The presence of smoke in the diesel engine exhaust is an indication of poor combustion resulting from some malfunction, maladjustment or non-proper fuel. For this reason the measurement of smoke emission is a widely agreed indication of engine technical state. Experiments have shown that the fuel economy penalty and smoke emissions are linearly related. Smoke may be defined as particles, either solid or liquid (aerosols) suspended in the engine's gaseous exhaust stream which obscure, reflect or refract, or both, visible light. Diesel

engine exhaust smoke can be categorized under two headings: (1) Blue/white in appearance under illumination, and consisting of a mixture of fuel and lubricating oil particles in an unburnt, partly burnt, or cracked state; (2) Grey/black in appearance and consisting of solid particles of carbon formed during fuel combustion [1].
Visible smoke emissions of diesel vehicles require special attention, as a suitable measure of engine PM emissions, and also due to their unpleasant odor and potential road safety hazard of reduced visibility from black smoke.
There are three necessary conditions for the control of diesel smoke emission:

- correct operation of the fuel injection system and especially adequate adjustment of the injection timing and a good maintenance of air filters;
- use of appropriate fuel;
- correct vehicle loading during operations and avoidance of vehicle overloading.

Various mandatory inspection schemes are currently applied to diesel engine powered vehicles (DEPV) in use worldwide. Regulations stipulate opacity limits for diesel black smoke emissions at the time of inspection. As a result of technological developments in the field of DEPV, such as high injection pressure and electronic control of injection, as well as the substantial improvement of diesel fuel quality, a dramatic reduction of smoke (and PM) emissions has been achieved, typical for diesel engines of new generations.
In many cases the new smoke levels are not reflected in the stipulated opacity limits of the existing regulation in Israel. Thus, due to the great difference between the allowed maximal smoke opacity limits and the smoke level recorded on the plate pursuant to council Directive 72/306/EEC, there are situations when a DEPV can pass the annual test with excessive smoke emission, because of engine malfunction or maladjustment [2].
The need to improve the existing inspection methods of smoke emissions by in-use DEPV is now a very serious problem not only for Israel, but for other countries too. The increasing severity of the environmental legislation on the one hand, and increasing the world production of DEPV and their rapid penetration in various countries worldwide (like Germany, France, Italy, Great Britain, Austria, Japan, Korea, etc.) on the other hand, call for the necessity of this improvement.
The reason for increasing the production of DEPVs in general and diesel cars in particular is technological progress and mainly because they are, on average, 20-30% more fuel-efficient than gasoline engines. Therefore, they also emit less greenhouse gases.
In Israel, the public transportation is based on diesel engine propulsion. As a result, the transportation diesel fuel consumption in 2003 reached about 48% of the total transport fuel consumption (expressed in mass units).
The main objective of this work was to develop a method of diesel smoke emission measurement, which will be suitable for use in the framework of I/M procedures and will allow better enforcement of regulations for various vehicle generations.

## METHODS OF IN-SERVICE SMOKE TESTS IN VARIOUS COUNTRIES

Test methods of short in-service smoke tests in various countries are summarized in Table 1, according to [3,4,5].

| | |
|---|---|
| Free acceleration test<br>- from idle<br><br><br><br><br>- from raised idle | The EU countries and Israel according to the Directive 96/96/EC and Denmark, Finland, Belgium, Italy, Netherlands, Poland, Russian Federation Malaysia, Singapore, South Korea, Argentina, Colombia (according to national regulation; US Federal for heavy-duty vehicles, according to the snap acceleration test.<br>Switzerland, Japan, Greece and Austria (according to national regulations) |
| Inertia controlled acceleration test | Not applied |
| Lug down test | Not applied |
| Single steady speed test<br>- On the road<br>- On chassis dynamometer | <br>Sweden<br>Israel |
| Road test on slope | Spain |

Table 1: Application of methods for short in-service tests in various countries [3,4,5].

This table shows that only in Israel the diesel vehicle annual test is performed under load at single steady speed on a chassis dynamometer. Only for long trailers, very high trucks and diesel vehicles with two or three driving axles, the test is performed under free acceleration conditions. The test procedure is as follows: after the diesel vehicle is installed on the chassis dynamometer rollers, the engine is accelerated up to the maximum rpm corresponding to the maximum power, and then the rpm is reduced by 15% while maintaining the full load, and then the smoke is measured with a partial flow opacimeter. As mentioned above, modern diesel engines are designed for low smoke emission levels. Thus, using the common limit, as it is applied today in Israel, may provoke improper maintenance of vehicles and may also lead to rather improper enforcement of the regulations regarding diesel smoke emissions. Another disadvantage of the method used today is high engine speed during the smoke test (especially for diesel passenger cars and light commercial vehicles) that is sometimes met by drivers' objections. If the loaded smoke test by single constant steady speed is conducted correctly, it can provide better results in comparison with the free acceleration test, whose results strongly depend on experience and qualification of the examiner.

## NEW METHOD PROPOSED FOR SMOKE EMISSION MEASUREMENTS

The proposed test method is based on smoke measurements under full load conditions at constant intermediate engine speed, using a simple chassis dynamometer without inertia masses. Results of the smoke measurements at full load conditions in the official type approval test according to the 72/306/EEC Directive are used as reference values for the definition of the smoke limit values for the I/M test, which will be different for various vehicle types and generations. Thus, automatic updating of the emission limits for new vehicle generations will be guaranteed. For better understanding of this proposed method, Table 2 presents results of smoke emission values at six operating regimes (points, numerated

I-VI), from the certificates of the official type approval test for four diesel engines (two light-duty vehicles and two heavy-duty vehicles). The last row in the Table shows the engine speed during the smoke test, as it is performed today in Israel. The recommendation emerging from the present work is to perform the smoke emission test for I/M programs by using the engine speed from the six measurement test points of the official type approval test as follows: engine speed from test point IV for diesel vehicles under 3.5 ton and engine speed from test point III for heavy-duty vehicles.

| 1 | | | 2 | | | 3 | | | 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3500 rpm-75 kW<br>4650 rpm max | | | 3800 rpm-89.5 kW<br>3800 rpm max | | | 1800 rpm-250 kW<br>2100 rpm max | | | 280 kW-2100 rpm<br>2330 rpm max | | | Test point |
| Smoke | Speed | | Smoke | Speed | | Smoke | Speed | | Smoke | Speed | | |
| $m^{-1}$ | rpm | %* | $m^{-1}$ | rpm | %* | $m^{-1}$ | rpm | %* | $m^{-1}$ | rpm | %* | |
| 0.25 | 3500 | 100 | 0.3 | 3800 | 100 | 0.06 | 1800 | 100 | 0.08 | 2100 | 100 | I |
| 0.28 | 3115 | 89 | 0.3 | 3382 | 89 | 0.05 | 1640 | 91 | 0.07 | 1880 | 89 | II |
| 0.28 | 2730 | 78 | 0.4 | 2964 | 78 | **0.05** | **1480** | **82** | **0.05** | **1660** | **79** | **III** |
| **0.22** | **2345** | **67** | **0.35** | **2545** | **67** | 0.06 | 1320 | 73 | 0.05 | 1440 | 68 | IV |
| 0.22 | 1960 | 56 | 0.35 | 2128 | 56 | 0.07 | 1200 | 66 | 0.10 | 1220 | 58 | V |
| 0.45 | 1575 | 45 | 0.85 | 1710 | 45 | 0.07 | 1160 | 64 | 0.32 | 1000 | 47 | VI |
| 2975** | | | 3230** | | | 1530** | | | 1785** | | | |

* Engine speed as percentage of speed at maximum engine power.
** Engine speed during the actual smoke test.

Table 2: Results of smoke emission measurement under full load conditions according to Directive 72/306/EEC for different engines.

In this new smoke emission test procedure, it is proposed that the smoke limit value does not exceed by more than 0.5 $m^{-1}$ the smoke level value, as measured during the official type approval test according to the 72/306/EEC Directive, and this is valid for each diesel engine type. For the four diesel engines in Table 2, the proposed smoke emission limit values for the I/M test are presented in Table 3.

| Diesel Engine Type | Test Point | Engine Revolutions for Smoke Emission Test, rpm | Smoke Density Limit, m-1 | Smoke Opacity Limit, HSU |
|---|---|---|---|---|
| 1 | IV | 2345 | 0.22+0.5=0.72 | 27 |
| 2 | IV | 2545 | 0.35+0.5=0.85 | 31 |
| 3 | III | 1480 | 0.05+0.5=0.55 | 21 |
| 4 | III | 1660 | 0.05+0.5=0.55 | 21 |

Table 3: Proposed smoke emission limits for I/M tests for four different diesel engines.
The feasibility of the proposed method was checked experimentally on a number of vehicles. Israeli Ministry of Transport is currently working on the preparation of a large-scale pilot, where the new method will be tested in the framework of real annual vehicle tests (I/M).

## CONCLUSIONS

1. A comprehensive review of available national and international standards dealing with smoke emission measurements for Inspection and Maintenance (I/M) tests was carried out.
2. The proposed test method is based on smoke emission measurements under full load conditions at constant intermediate engine speed, using a simple chassis dynamometer without inertia masses.
3. It is proposed to use the smoke emission test results obtained during official type approval tests as reference values. This will ensure automatic updating of smoke emission limits for the new vehicle generations.

## REFERENCES


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