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DIESEL ENGINE VISIBLE EMISSIONS - COMPARISON OF TRACTOR AND ROAD VEHICLE STANDARDS

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Abstract: *The paper presents an analysis of two visible emissions standards for tractor and road vehicle diesel engines. For a certified emission diesel engine according to road use (ECE Regulation 24) it is presented the procedure of certification according to tractor use (Directive 77/537/EEC). Experimental work was performed on the dynamometric bench being measured declared performances and emissions. Some discussions are made on light absorption coefficients- measures and limits.*

Key words: *tractor diesel engine, visible emissions, certification.*

1. Introduction

Heavy duty diesel engines are used predominantly to power heavy trucks, buses and tractors. The major concern over diesel engines is to control the exhaust gas pollutants according to legislation, without impeding performance indicators such as power, torque and fuel consumption. The exhaust gas pollutants include CO_2, H_2O, NO_x , HC and CO, but also “visible pollutants” that create optical effects in the exhaust (smoke) and are known also as diesel particulates. For tractors, the pattern of engine operation is different than in running on road vehicles so the limits on exhaust gas emissions, mainly visible pollutants, known also as smoke, will provide dissimilar requirements, expressed in separate standards.

Research work literature on diesel powered agricultural tractors dealt with fuel economy and operation modes identifying the correlation with specific speeds and loads [2]; in terms of emissions, experimental investigations revealed the possibility of replacing conventional diesel fuel with biodiesel [1, 3].

In European Union the legislation is divided according to the type of vehicle or machinery and its use; for tractors, the Directive 77/537 of the European Economic Community (EEC) [4] dealt with emission of pollutants from diesel engines for use in wheeled agricultural or forestry tractors and for road vehicles. Regulation No. 24 of the Economic Commission for Europe of the United Nations (UN/ECE) [5] defines provisions for approval with regard to visible pollutants of motor vehicles equipped with compression-ignition engines. Regarding the implementation timetable, the first

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emission standards for tractors (2003) were strongly delayed from the first emission standards for road vehicles (Euro I, 1992) and that trend is still maintained [6].

As the aforementioned standards present significant similarities, the paper intends to analyze if the certification of the same diesel engine according to one standard would imply the meeting of demands of the second one. The idea of this paper started from a real life demand of using a diesel engine already certified for road vehicle operation according to Regulation 24 to be further certified according to Directive 77/537, in order to be used on a tractor.

2. Legislation Analysis

The Directive 77/537 deals with emission of pollutants from diesel engines for use in wheeled agricultural or forestry tractors. By agricultural or forestry tractor is meant “any motor vehicle, fitted with wheels or endless tracks, having at least two axles, the main function of which lies in its tractive power and which is specially designed to tow, push, carry or power certain tools, machinery or trailers intended for agricultural or forestry use, which may be equipped to carry a load and passengers”. The Directive applies only to „tractors fitted with pneumatic tyres and which have two axles and a maximum design speed between 6 and 25 km/h” [4].

Regulation 24 deals with „the approval of a compression-ignition engine with regard to the limitation of the emission of visible exhaust pollutants from the engines” which are intended for fitting to road vehicles [5].

The preliminary investigation of the aforementioned standards identified the following similarities (mostly identities) and differences, summarized in Table 1.

Similarities and differences between visible pollutants standards Table 1

<table>
<tr><th></th><th>Directive 77/537</th><th>Regulation 24</th></tr>
<tr><td rowspan="6">Similarities</td><td colspan="2">- both measure the same visible pollutant</td></tr>
<tr><td colspan="2">- the pollutant measuring method is the same - light absorption or opacity, k, [m^{-1}]</td></tr>
<tr><td colspan="2">- the procedure of measurement includes the same two tests at steady speed and in free acceleration</td></tr>
<tr><td colspan="2">- technical specification of the opacimeter is identical</td></tr>
<tr><td colspan="2">- identical limits of threshold values of k</td></tr>
<tr><td colspan="2">- exhaust gas flow rate calculation is common</td></tr>
<tr><td rowspan="6">Differences</td><td>- the correction factor depends only on atmospheric conditions</td><td>- the correction factor depends both on atmospheric conditions and engine fuel flow rate</td></tr>
<tr><td colspan="2">- the atmospheric factor formula has dissimilar exponents</td></tr>
<tr><td>- the steady speed test is done at a load of 80% of rated power</td><td>- the steady speed test is done at full load</td></tr>
<tr><td>- selection of minimum rated speed - the highest of the following two engine speeds:
- 55% of the engine speed at the rated power;
- 1000 rpm.</td><td>- selection of minimum rated speed - the highest of the following three engine speeds:
- 45% of the engine speed at the rated power;
- 1000 rpm;
- minimum speed permitted by the idling control.</td></tr>
<tr><td>- auxiliary equipment according to net power standard (ISO, SAE, DIN, BS).</td><td>- explicit list of auxiliary equipment (with and without) during tests.</td></tr>
<tr><td colspan="2">- slightly different in fuel characteristics (density, sulphur content, cloud point, water content, strong acid number)</td></tr>
</table>

Among all the factors influencing engine visible emissions can be considered engine load and speed and quality of the fuel, mainly sulphur content, aromatic content and final temperature of distillation.

3. Engine Testing

A diesel engine previously certified according to Regulation 24 was tested according to Directive 77/537, being presented the procedure step-by-step.

3.1. Engine Description

The tested engine was manufactured at Motoare AB company (Brașov, Romania) being provided to power trucks and buses. The six-cylinder, naturally-aspirated engine codification is D2356HMV with series number 18230 and the main engine specifications are presented in Table 2 [7].

Engine characteristics Table 2

Engine type	**Diesel**
Bore x Stroke [mm]	123 x 150
Total displacement [L]	10.694
Compression ratio	18:1
Rated power [kW]	150
Rated speed [rpm]	2100
Maximum torque [N·m]	750
Maximum torque speed [rpm]	1400

The tests were performed on a dc-300 kW dynamometric test bench in Road Vehicle Institute - INAR Brașov. The engine was delivered by the producer with a fixed injection timing of 24° being equipped with:

- in-line injection pump, fitted with timing and speed regulator;
- fuel correction device;
- unloaded alternator;
- no compressor;
- fan and air filter;
- exhaust duct of the test bench.

As engine cooling agent was used the distilled water from the cooling system of the test bench. For the engine operation it was used diesel fuel according to standard EN 590 and lubricant with viscosity class SAE 15W30. The pressure loss on the test bench air intake was 250 mm column H_2O and 730 mm column H_2O on exhaust duct, measured at rated power. The engine was instrumented with temperature sensors (cooling liquid, oil and exhaust gas), pressure sensors (oil, air, exhaust gas), flowmeters (air and fuel) and connected to opacimeter, being running-in before the tests.

3.2. Atmospheric Factor

According to Directive 77/537, the atmospheric factor was calculated based on the absolute temperature *T* of the laboratory, expressed in Kelvin, and the atmospheric pressure *H*, expressed in mm column of Hg.

The factor *F* was calculated with the formula:

$$F = \left(\frac{750}{H}\right)^{0.65} \left(\frac{T}{298}\right)^{0.5}. \tag{1}$$

For a test to be recognized as valid, the factor *F* shall be included in the range $0.98 < F < 1.02$. During the test the ambient conditions from test bench were as follows:

- barometric pressure: 717 mm Hg ;
- ambient temperature: 16°C (289 K);
- relative humidity: 70%.

3.3. Measures and Correction of Performance

The conformity of the engine under test with the declaration of performance imposed the preliminary measurement of power, torque, hourly fuel consumption and specific fuel consumption at 80% of maximum power. The measures were corrected with atmospheric factor of 1.0186 imposed by Directive, according to formula (1). This factor affected power, torque and specific fuel consumption [7].

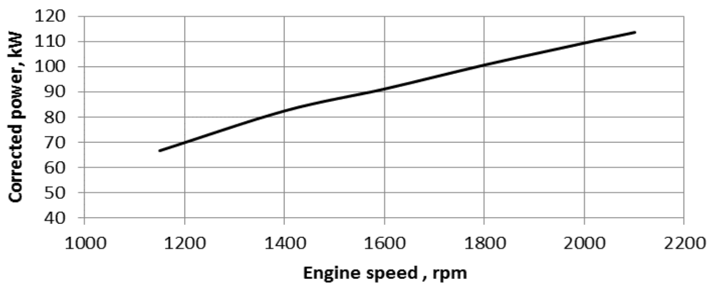

Fig. 1. *Part load (80%) - speed characteristic*

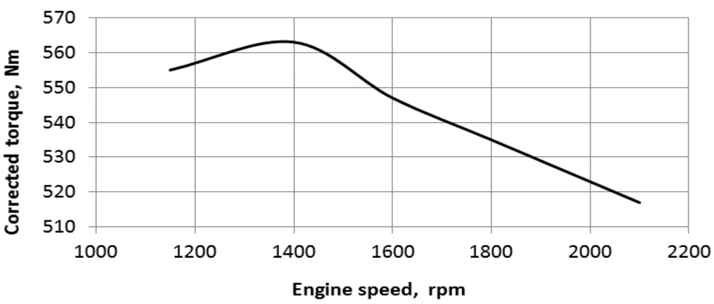

Fig. 2. *Torque-speed characteristic*

There were measured two types of fuel consumption, one is the hourly fuel consumption of the engine at part load (Figure 3) and the other is the specific fuel consumption which is calculated from hourly fuel consumption reported to part load power. The corrected values are presented in Figure 4.

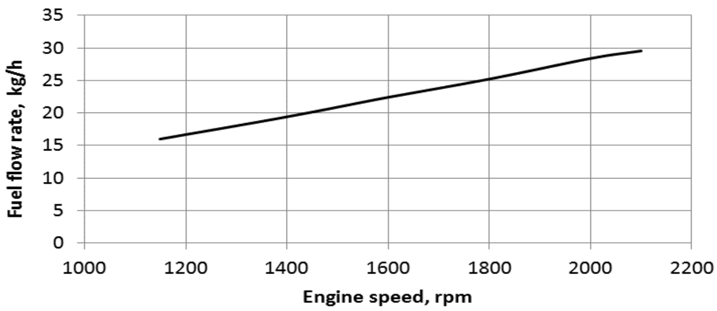

Fig. 3. *Hourly fuel consumption versus speed*

The specific fuel consumption was calculated using the hourly fuel consumption which was reported to the corrected power. It is expressed in unit g/kWh being a relevant indicator of the efficiency.

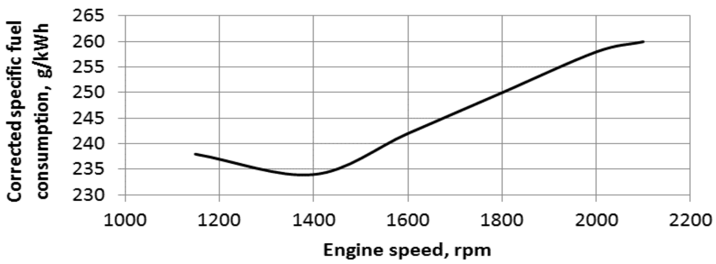

Fig. 4. *Specific fuel consumption versus speed*

The profile of the specific fuel consumption in Figure 4 has the lowest value at the speed of the maximum torque (1400 rpm) being in accordance with engine literature [8].

4. Visible Emission Measurement

The emission of pollutants by the engine tractor submitted for approval was measured according to two methods, relating respectively to tests at steady speeds and to tests under free acceleration. The measurements were performed with opacimeter AVL 465 in which the gas is measured in a confined enclosure with a non-reflecting internal surface; the effective length of light path being 430 mm. The opacimeter has two scales, a linear scale ranging from 0 to 100 and a logarithmic scale in absolute units of light absorption ranging from 0 to 4 m^{-1}.

4.1. Steady Speed Test

The opacity of the exhaust gases produced by the engine was measured with the engine running at 80% of the maximum load and at steady speed, in six points spaced out between that corresponding to maximum power and the higher of the following two engine speeds: 55% of the engine speed corresponding to maximum power and 1 000 rpm. For the tested engine the higher speed was 55% from the rated speed of 2100 rpm, meaning that the lowest speed was 1050 rpm. For each of the engine speeds at which the absorption coefficient was measured, the nominal gas flow was calculated by means of the following formula for four-stroke engines:

$$G = \frac{V \cdot n}{120} \quad (2)$$

with *G* - exhaust gas flow, in liters per second (l/s), *V* - total cylinder displacement of the engine, in liters (1), *n* - engine speed, in revolutions per minute (rpm). The threshold values indicated both in Directive 77/537 and in Regulation 24 are presented in Figure 5.

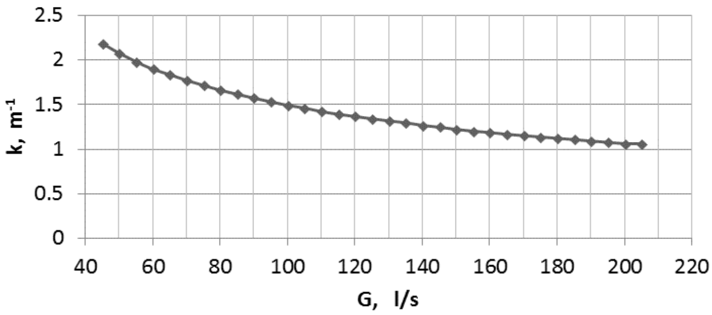

Fig. 5. *Limits of light absorption coefficient versus exhaust gas flow*

For the tested engine, the visible emission opacity was expressed in light absorption coefficient, *k*; its values were illustrated by linear interpolation of the six points in Figure 6, in black, solid line.

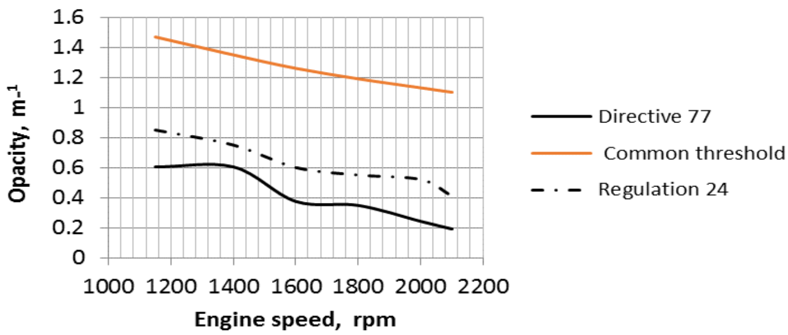

Fig. 6. *Light absorption coefficient versus speed*

The red line represents the threshold value of the visible pollutants opacity having the same limits admitted for Directive 77/537 and for Regulation 24. The dotted line represents the opacity of the same engine performed for 100% load according to Regulation 24 [9].

4.2. Free Acceleration Test

With the engine idling, the accelerator control was actuated rapidly, but not violently, to get the maximum fuel delivery from the pump.

The accelerator was kept until maximum engine speed was reached and the governor came into action. When this speed (cut-off speed) was reached, the accelerator was released until the engine reverted to idling speed. The operation was repeated six times and the values read in Table 3 shall be regarded as stabilized when four consecutive readings are situated within a band width of 0.25 m^{-1} and do not form a decreasing sequence [1].

Free acceleration test measures Table 3

No.	Idle speed (rpm)	Cutoff speed (rpm)	Acceleration time (s)	Opacity k (m^{-1})
1	593	2276	0.48	2.48
2	595	2281	0.48	2.32
3	596	2279	0.57	2.14
4	597	2274	0.57	2.04
5	598	2266	0.48	1.94
6	598	2264	0.57	2.13
Value X_M				2.06

The measured opacity X_M = 2.06 m^{-1} is the mean value of four readings (no. 3-6).

The corrected value of opacity, X_C, in free acceleration is: $X_C = X_M + 0.5 = 2.56$ m^{-1}.

The final result is the smallest value calculated from two:

- $X_C = X_M (S_L / S_M)$ in which S_M = 0.607 m^{-1} - the measured opacity in stabilized operation mode which is the closest to the prescribed limit and S_L =1.35 m^{-1} - the limited value of opacity corresponding to the speed at which S_M is measured.
- $X_C = X_M + 0.5 = 2.56$ m^{-1}.

Finally, X_C = 2.56 m^{-1}. The free acceleration test does not impose a limit to the visible emissions, it is just declared in the homologation documents. It can be used in the study of smoke emission of a given engine or for comparison of two similar diesel engines.

5. Conclusions

As illustrated in Figure 6, it may be concluded that visible emissions of the tested diesel engine, measured according to Directive 77/537 and Regulation 24, are much lower than the threshold limits.

Although both standards have the same limits of absorption coefficient k, the visible emissions at part load (80%) are lower than at full load (100%), so the Directive is more permissive than Regulation.

It may be assumed that an engine certified according Regulation would meet the requirement of Directive. The reverse assumption could not be true. An engine certified according to Directive 77/537, closer to limits, is not certain to be certified according to Regulation 24, because at higher load the absorption coefficient will be higher and may exceed the threshold values.

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