A comparative study of smoke emissions between idling regimes and high load regimes for a standard diesel direct injection car

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Abstract: The paper presents a study of smoke emissions for car Dacia Solenza 1.9D-SDI (63HP) which was produced by Renault in Romania. A similar engine can also be found on the Kangoo Express and Kangoo Passenger cars respectively. Smoke emissions are analyzed comparatively, between idling regimes and load regimes. Also are presented variations of engine speed, accelerator pedal position, fuel flow injected, automotive speed, which are taken using OBD II connection and Autocom CARS CDP+ Scanner. To simulate the load regimes chassis dynamometer V-Tech Dyno VT-2/B1 was used. A module for measuring the opacity of the exhaust gases was used, which is in the gas analyzer Ultimag 600. In graphics are shown variations of the opacity of exhaust gases between idling regimes and load regimes considered. The different pollutions levels with smoke are analyzed between idling regimes and low loads, respectively high loads. Conclusions about the level of pollution are stated. Also are make recommendations for operating regimes of the car, so as to reduce the level of pollution.

1. Introduction
In order to limit diesel particulate emission and reduce the pollution to meet the increasingly stringent emission regulations, awareness of the use of engine in low-pollution mode (according to the recommendations in this paper) and also the reduction of oil consumption rate becomes an important issue in the development, design and operation of diesel engines.

The present paper aims precisely to show the difference between the smoke index determined at idling speed by free acceleration from minimum speed to maximum idle speed and the one determined at the load regimes specific to the normal operating conditions, in case of a diesel direct injection car. On base of the experimental determinations made, we can indicate that low speed operating modes of up to 2500 [rpm] and acceleration positions over 70% are the ones that generate the biggest amount of smoke. To reduce smoke pollution, it is advisable to avoid operating at lower engine speeds and high loads. In the case of real operating regimes (operating regimes in load), the smoke level may exceed the maximum smoke level imposed by European anti-pollution legislation, this level of smoke being measured by free acceleration at idling speed between the minimum and the maximum rotation of engine.
The proportion of particulate emission of diesel has a relationship with the structure and type of the engine, operating conditions and the physical and chemical properties of the oil. The oil consumption rate significantly influences the particulate emission and the performance of the diesel engine [8].

2. Equipment used for experimental studies

The equipment used for experimental determinations includes a car, diagnostic equipment and an analyzer of exhaust gases.

The car used in the study, was Renault-Dacia-Solenza 1.9D-SDI with the characteristics indicated in the following table, from [3].

| Maximum power | Maximum rotation of engine | Engine type | Engine volume | Cylinders number | Type of fuel and fuel system | Environmental standard | Maximum authorized weight |
|---------------|----------------------------|-------------|---------------|------------------|----------------------------|------------------------|--------------------------|
| 63            | 4500                       | F8Q         | 1870          | 4                | Diesel/Standard diesel injection-SDI | EURO III               | 1460                     |

The equipment used to diagnose the car and take over the operating parameters is of type Autocom CARS CDP+, [4], [5]. The gas type analyzer is Johnson Controls – Ultimax 600, 800-65 model, produced by Johnson Controls Automotive Electronics in France. The analyzer can measure the opacity coefficient (table 2) in the case of engines with diesel fuel.

| Emission/Characteristic | Range of variation          | Precision   |
|-------------------------|-----------------------------|-------------|
| Opacity coefficient     | 0-9.99 [m⁻¹]                | 0.01 [m⁻¹]  |
| Rotation range          | 300-7000 [rpm]              | 10 [rpm]    |
| Oil lubrication temperature | 0-150 [°C]                | 1 [°C]      |
| Exhaust gas temperature | 0-150 [°C]                  | 1 [°C]      |

In accordance with the European provisions, for diesel-fueled cars, at the periodic technical inspection [7], the smoke index is checked, which must fit as follows:
- for unpowered diesel engines, the smoke index \( k \leq 2.5[m^{-1}] \).
- for turbocharged diesel engines with pollution norms up to and including EURO 3, the smoke index \( k \leq 3[m^{-1}] \).
- for turbocharged diesel engines that have the pollution standard EURO 4, EURO 5, EURO 6, the smoke index \( k \leq 1.5[m^{-1}] \).

The determination shall be made at idling speed by free acceleration from minimum idle speed to maximum speed (the speed limited by the regulator) according to [7]. The lubricating oil temperature must be \( t_{oil} \geq 80[°C] \). The final result will be the arithmetic mean of at least 3 determinations performed under the same conditions.

The present paper aims precisely to show the difference between the smoke index determined in the idle regime and the one determined at the load regimes specific to the normal operating conditions. The roller stand enables the dynamical determination of the engine's power and torque, as well as of the power and torque of the vehicle's engine wheels.

The V-Tech Dyno VT-2 / B1 Chassis dynamometer has been used, which has the following features:
- Maximum load on the axis 3000 kg.
- Number of axes - 1 axis.
- Maximum speed 300 [km/h].
- Maximum engine power measured 600 [HP].
- Minimum external wheel diameter 400 [mm].
- The TELMA eddy-current electric brake with a maximum torque of 800 [Nm] / 1000 [rpm], with a precision of 0.1% for inertial mode and 1% for brake mode respectively.

To perform the load tests, the constant speed method was used. *Constant rpm mode* allows maintaining the desired rpm rate by applying additional load with eddy current brakes. Due to the increasing resistance introduced by the electric brake as the acceleration increases, the engine speed is kept approximately constant at the desired value.

In the tuning panel figure 1, current power on wheels is shown which allows on-line tuning of installation and obtaining the highest power possible. Press the acceleration pedal home, the computer controlling the eddy current brakes will restrain the engine to maintain the rpm rate set earlier at completely pressed accelerator pedal. During tuning it is possible to change rpm rate threshold on the computer, by the mouse.

3. **Experimental determinations**

Using the equipment presented, experimental determinations were carried out for opacity coefficient at idling regimes and load regimes.

At the same time, variations in engine speed, accelerator pedal position, fuel flow (expressed in mm³ / stroke) and running speed (load modes only) were taken over.

Load determinations were performed, considering the variation of the accelerator pedal position between 25% and 100%, considering the constant speed method, the speeds considered being 1500, 2000, 2500, 3000, 3500 and 4000 [rpm].

In the paper are shown in figure 2, 3, 4, the variations of the sizes indicated as constant speeds, the values of 1500, 2000 and 3000 [rpm]. Autocom CARS CDP + was used to take up the indicated variations.

The evolution of the measured values of the smoke index, for quasi-stationary regimes (quasi-stationary regimes near to stationary regimes) of average and high loads, is shown in figure 5.

According to the variations in figure 2, 3, 4, 5, it can be indicated that with the increase of the accelerator pedal position, the injected fuel flow will also increase, its substantial increase being after the 60% acceleration position so that at acceleration of 100%, the fuel flow reaches a maximum of 33 mm³/stroke.
Figure 2. Values obtained at approximately constant rotation 1500 [rpm] in load, with diagnostic equipment.
Figure 3. Values obtained at approximately constant rotation 2000 [rpm] in load, with diagnostic equipment.
**Figure 4.** Values obtained at approximately constant rotation 3000 [rpm] in load, with diagnostic equipment.
Following the evolution of the smoke index, measured at quasi-stationary regimes, (quasi-
stationary regimes near to stationary regimes) for various speeds and loads, according to the variations
in figure 5, the following can be indicated:
- for speeds $<2500$ [rpm] and high loads corresponding to the acceleration positions $\geq 0.75$ (75%),
  the smoke index is $> 2.5$ [m$^{-1}$].
- thus, the level of smoke measured at these quasi-stationary regimes exceeds the level of smoke
  measured in the dinamic idle regime (see figure 8) as well as the limit smoke level specified in the
  anti-pollution legislation (for unpowered diesel engines, the smoke index $k \leq 2.5$[m$^{-1}$]).
- for speeds $\geq 2500$ [rpm] and average and high loads, smoke index $\leq 2$ [m$^{-1}$].

Following the determination of quasi-stationary speed and medium and high loads, the following can be
indicated:
- at lower speeds and high loads (such as maximum torque regimes), even under quasi-stationary
  regimes, the smoke level increases, surpassing the level of smoke measured in the idle mode as
  well as smoke levels indicated in the anti-pollution legislation (for a car equipped with an
  unpowered diesel engine, the smoke index $k \leq 2.5$[m$^{-1}$]).
- according to the determinations made and the variation of the smoke index in figure 5, for the
  positions of the acceleration disposed between 75-100% and the speeds of 1500-2000 [rpm], the
  smoke index reached values of 2.5-3.1 [m$^{-1}$].
- for high load conditions it is advisable that the engine run at speeds above 2500 [rpm], as in this
  case the level of smoke will drop.

Figure 5. Smoke at different rotation of engine and accelerator pedal positions.
- according to the determinations made and the variation of the smoke index in figure 5, for positions of acceleration disposed between 75-100% and speeds 2500-4000 [rpm], the smoke index reached values of 1.25-2 [m$^{-1}$].

The reduction of smoke at high speeds and medium and high loads is explained by the favorable influence of turbulence increase on the rate of combustion of the fuel mixture as well as the greater amount of air introduced into the combustion chamber with the increase in speed.

Determinations have also been made at quasi-stationary regimes (quasi-stationary regimes, near to stationary regimes) for idle speeds between 1000 and 4000 [rpm], the variation of the accelerator pedal position being between 0% and 47%.

Figure 6 shows the variations in engine speed, accelerator pedal position and injected fuel flow, expressed in mm$^3$/stroke.

According to the variations in figure 6, it can be indicated that with the increase of the accelerator pedal position, the injected fuel flow will also increase slightly, varying between 5 and 9 mm$^3$/stroke, with a maximum of 3.6 times lower than that at the full load regime, as can be seen from figure 2, 3, 4.

**Figure 6.** Values obtained with diagnostic equipment, at idling regimes.
The evolution of the measured values of the smoke index, for quasi-stationary idle modes, is shown in figure 7.

Figure 8 shows the maximum opacity index for fast acceleration between minimum and maximum engine speed (the speed limited by the regulator), in accordance with the provisions of European anti-pollution legislation and [7].

![Figure 7. Smoke at idling regimes at different rotations.](image)

Following the evolution of the smoke index measured at quasi-idle idle speeds for various speeds, according to the variation in figure 7, the following can be indicated:
- for speeds around 2000 [rpm] and speeds above 3500 [rpm], the smoke index has values above 0.18 [m⁻¹].
- in terms of quasi-stationary regimes (quasi-stationary regimes, near to stationary regimes), the smoke index is 10 times lower than in the case of sudden acceleration between the minimum and maximum speed, as shown in figure 8.

![Figure 8. Maximum opacity index for fast acceleration between minimum and maximum speed.](image)
4. Conclusion
According to the experimental results, conclusions are:
- at lower engine speeds (below 2500 rpm) and high load, corresponding to 75% acceleration positions, even under quasi-stationary modes, the smoke level increases, surpassing the level of smoke measured in idle mode, as well as the level of permitted smoke index, as indicated in the anti-pollution legislation (for a passenger car equipped with an unpowered diesel engine, the smoke index limit is $k \leq 2.5$ $[m^{-1}]$). According to the determinations made and the variation of the smoke index in figure 5, for the positions of the acceleration disposed between 75-100% and the speeds of 1500-2000 $[rpm]$, the smoke index reached values of 2.5-3.1 $[m^{-1}]$.
- for high load conditions it is advisable that the engine run at speeds above 2500 $[rpm]$, as in this case the level of smoke will drop.
- for stationary idle modes, the smoke index has low values.
- the smoke level measured in the dynamic mode at idle speed between idle and maximum speed does not exceed the permissible limit $k \leq 2.5$ $[m^{-1}]$, the measured value being $k = 1.86$ $[m^{-1}]$.
- by comparing the smoke index between idle and load cycles, it can be indicated that low speed operating modes of up to 2500 $[rpm]$ and acceleration positions over 70% are the ones that generate the higher amount of smoke; to reduce smoke pollution, it is advisable to avoid operating at lower engine speeds and high loads, such as high engine torque modes.

5. References
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