Automotive Engine Air Cleaners – Maintenance Investigations

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Abstract: - The dust particles from the atmospheric air that pass through the air cleaners of the internal combustion engines heavily influence their wear. The main purpose of air filters is to reduce the quantity of particles that reach the burning chambers of internal combustion engines. To achieve this purpose, an increased importance must be given to maintenance activity. The replacement of air cleaners must be made by understanding the implications of their premature or tardy replacement over the life of the engine. In this paper were tested air cleaners of the same type measuring the values for: pressure drop of several air cleaners at the time of their replacement; filtration efficiency of new and used filters; and the size of dust particles that pass through new and used air cleaners. This paper aims to highlight the extent to which the replacement of air cleaners based on the distance travelled by the car or the usage time (in kilometres or years) is appropriate for protecting internal combustion engines.

Key-Words: - air cleaners, pressure drop, efficiency, particle size, replacement period.

1 Introduction
The life of an internal combustion engine is influenced by a multitude of parameters. These include the contamination of the intake air with mineral, very tough impurities with sharp irregular shapes. The penetration of impurities inside the burning chamber and forward to the lubricant reduces the lifetime of the engine. In paper [1] is specified that 80% of the cases, the engines’ lifetime is limited by the consequences of the wear.

Atmospheric air contains lots of particles with physical-chemical properties influenced by the geographic region, clime, season, urban or extra urban area [2], [3], [4].

The main sources of the particles from the roads are: industrial ones; dust from the agricultural fields carried by the wind; particles resulted from road wear and motor vehicles components wear; exhaust particles from the engines [5].

The air admission system is the main source of impurities (contaminants) that reach inside the engine. Choice and maintenance of the air cleaners are important activities in reaching a longer lifetime of the engines, ensuring high levels of energetic, economic and reliability performances.

The performances of the air cleaners are evaluated by the next main criteria:

- a high filtering efficiency over the entire air cleaner’s service life;
- reduced gaso-dynamic resistances over the entire service life;
- high storage capacity of the impurities.

Next some terms are defined:
- efficiency - ability of the air cleaner or the unit to remove contaminant under specified test conditions, [6];
- absolute filter—the filter downstream of the unit under test to retain the contaminant passed by the unit under test [7];
- differential pressure [6] (pressure drop [7]) - difference in static pressure measured immediately upstream and downstream of the unit under test.

2 Literature references
In paper [8] is defined the service life: The useful functional life of an engine air induction filter, in order to protect the engine without any appreciable performance degradation.

Setting the maintenance intervals for the air cleaners should be made considering the construction-function and exploitation conditions of the motor vehicles.

The main replacement criteria are:

- the distances covered with the same air cleaner (the main criteria);
- the usage period;
- reaching a rise in pressure resistances for the used air cleaners compared to the new ones.

Air filters are generally replaced when they look dirty at a simple visual inspection, without a complete understanding of the maximum efficiency conditions. Thus, the air cleaners are replaced unnecessarily, being under their service life [9].

Technical specifications of the engines’ air cleaners are continuously changing to sustain the rise of the engine performances for a longer service life.

Air cleaners, by pressure drop, develop gasodynamic resistances in the admission system, which at high levels cause a fall of the engine’s power [10].

In paper [11] are presented usual values for the initial pressure drop of the air cleaners. For new air cleaners, the value is about 300÷400Pa; these values are determined for a maximum consumed debit by the car’s engine.

Papers [12] and [13] measured the pressure drop of new air cleaners considering ISO5011 standards. For the cellulose fiber air cleaner, the pressure drop is 380Pa at an air debit of 300m³/h [12]. In paper [13] the pressure drop for different materials of the air cleaners is about 100-250-350Pa at an air debit of 155.4m³/h. Those values represent the pressure drop strictly related to the air cleaners, without considering air cleaner’s case.

Papers [8] and [9] suggest that the air cleaners must be replaced when the pressure drop rises by 2500Pa, compared to the initial value measured on the new filter.

During time, an air cleaner efficiency increase. In paper [1] is presented a case of a truck air cleaner. With an initial filtering efficiency of 99.53%, the penetration of the filtering material made of cellulose fibre, in the first part of the service life, is 16 times higher than the average of the entire usage period. This period is considered immediately after the beginning of usage up to a filter’s load of 10.8g/m² with dust, being equivalent of 3% of the entire service life.

A new air cleaner, depending on the type of the filtering material, has an initial efficiency of 96% up to 99.6%. At the end of the service life, the filtering efficiency reaches 99.9% according to [1], [15], [16], [17].

In paper [1] are presented different studies, all of them concluding that exist a linear dependence between the dust concentration and the engine’s wear. The dimensions of the dust particles that pass through the air cleaner profoundly influence the engines wear at the level of the piston’s ring. The particles with dimensions of 4-5µm produce a significant wear, while the particles up to 2µm that penetrate the cleaner have no major influence on the engine’s wear. Particles bigger than 5µm represents a major factor of wear but they pass in small amount by the usual air cleaners and are completely stopped by the high performance air cleaners.

The same conclusions are presented in paper [5]. It states that the engine’s wear depends on the size of the abrasive particles and the thickness of the dynamic oil film between the kinematic couples. Particles having similar diameters with the oil film produce the main wear. The thickness of dynamic oil film is higher than 1µm.

Paper [5] presents the fact that particles smaller than 10µm, namely 0-5µm and 5-10µm produce four times higher wear than the particles with dimensions between 10-20µm.

3 Experiment

The study refers to the pressure drop measured in laboratory conditions as well as measuring the filtering efficiency for new and used air cleaners. The results are used to establish if the air cleaners are prematurely replaced during service life, before reaching the complete filtering capacity, and the consequences of this action.

The laboratory tests were made on a special stand designed and built according to ISO 5011 standard. The block scheme of the stand is presented in fig.1.

The laboratory stand permits:
- to measure the air flow debit that passes through the air cleaner;
- to set the air debit;
- to measure the restriction;
- to measure the pressure drop;
- to control the dust loading of the tested air cleaner;
- to measure the pressure, temperature and atmospheric humidity;
- to dry the air cleaners and the dust;
- weighing the air cleaners.

The tested air cleaners are for K4M and K7M Renault engines used on Dacia Logan cars manufactured between 2004-2010. The two engines use the same air filter case. In that air filter case is possible to put on air filters from different manufacturers.

For this type of car, the designer recommends the replacement of the air cleaner at 15,000 km or every year, for the car models up to 2008. For those cars manufactured between 2008-2010 at every 20,000 km or two years [18], [19].
The tested air cleaners are all the same type. They are used in service stations for preventive maintenance and are approved by the manufacturer. New and used air cleaners were tested. The used filters are from cars in usage. After the extraction of the air cleaners from the cars, they were kept in plastic bags to prevent the humidity absorption from the environment and to lose the dust.

Table 1 indicates the real data from exploitation and the environment where the cars were used.

Table 1 Exploitation data for the used air cleaners

<table>
<thead>
<tr>
<th>No.</th>
<th>Air cleaner</th>
<th>Covered distance [km]</th>
<th>Length of time [months]</th>
<th>Regional movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>U1</td>
<td>&lt;15000</td>
<td>12</td>
<td>combined***</td>
</tr>
<tr>
<td>2</td>
<td>U2</td>
<td>&lt;15000</td>
<td>12</td>
<td>combined***</td>
</tr>
<tr>
<td>3</td>
<td>U3</td>
<td>15000</td>
<td>12</td>
<td>combined***</td>
</tr>
<tr>
<td>4</td>
<td>U4</td>
<td>48000</td>
<td>33</td>
<td>extraurban**</td>
</tr>
<tr>
<td>5</td>
<td>U5</td>
<td>17000</td>
<td>34</td>
<td>extraurban***</td>
</tr>
<tr>
<td>6</td>
<td>U6</td>
<td>15000</td>
<td>12</td>
<td>combined***</td>
</tr>
<tr>
<td>7</td>
<td>U7</td>
<td>15000</td>
<td>12</td>
<td>combined***</td>
</tr>
<tr>
<td>8</td>
<td>U8</td>
<td>15000</td>
<td>12</td>
<td>combined***</td>
</tr>
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<td>9</td>
<td>U9</td>
<td>15000</td>
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<td>combined***</td>
</tr>
<tr>
<td>10</td>
<td>U10</td>
<td>15000</td>
<td>12</td>
<td>combined***</td>
</tr>
<tr>
<td>11</td>
<td>U11</td>
<td>15000</td>
<td>12</td>
<td>combined***</td>
</tr>
<tr>
<td>12</td>
<td>U12</td>
<td>15000</td>
<td>12</td>
<td>urban*</td>
</tr>
<tr>
<td>13</td>
<td>U13</td>
<td>15000</td>
<td>12</td>
<td>combined***</td>
</tr>
<tr>
<td>14</td>
<td>U14</td>
<td>15000</td>
<td>12</td>
<td>combined***</td>
</tr>
<tr>
<td>15</td>
<td>U15</td>
<td>51000</td>
<td>31</td>
<td>extraurban**</td>
</tr>
</tbody>
</table>

*preponderant used in urban areas;
**preponderant used in extra-urban areas;
***used approximately equal in extra-urban and urban areas.

The tests were made at the highest air debit of 208m³/h consumed by the Renault K7M engines.

3.2 Measuring the filtering efficiency

During the experiments for determining the filtration efficiency, three new air cleaners and two used ones (the U1 and U13 air cleaners) were tested. The U1 was slightly used, confirmed by the covered distance (see table 1) and its appearance, being less clogged compared to other used filters.

The state of the U13 filter is common to all other tested filters. The efficiency of the air filters was determined after inserting 20g of dust inside the air cleaners. This represents the initial filtering efficiency for the used filters according to [1].

The air debit through the filters was 208 m³/h. The dust used in testing was obtained from the streets of Bucharest. It was sifted in three parts: first with dimensions smaller than 200µm, second with dimensions smaller than 100µm and the third part smaller than 40µm.

In order to meet the requirements of ISO 12103-1 standard, the dust used in experiments has 90% particles smaller than 40µm and 10% particles with dimensions between 40-100µm.
The absolute filter has a progressive structure composed of four layers of nonwoven tissues (fig. 2).

The measuring devices meet the ISO 5011 standard measurement accuracy.

During experiments, the pressure and temperature of the environment are measured. The pressure drop values are corrected to standard conditions according to paper [6].

Before use, the dust was heated in a vessel up to temperatures over 100°C to eliminate the humidity as standard recommend [6]. Thus, the humidity was eliminated and then the air filters were weighed.

### 3.3 Image analyse of the samples from the absolute filters

By taking and analysing the images of filtering materials of absolute filters, the aim is to determine the dimensions of the particles passed through the air cleaner and their percentage in all particles present in the studied sample.

To determine the efficiency of every air cleaner, an absolute filter was used. From every absolute filter, samples of filtering material were taken from the central zone (fig. 2).

The images obtained by an electron microscope were processed using ImageJ software, applying "Analyse Particles" function [21].

Every image taken by microscope has on the bottom side a legend containing a segment of known length. The scale is selected using that segment with known length.

After the scale selection, the legend is deleted to avoid influencing the result of the analyse.

The ImageJ software by function Analyse Particle shows an image that contains identified particles (fig. 4), the number and the area of every particle from that image.

To determine the linear dimension of particles an assumption over the shape of a particle was made – a particle can be considered a square whose side is calculated based on the particle area.

The total number of particles identified in every sample was divided into groups of dimensions: 0-2µm; 2-5µm and 5-10µm. According to the papers [1] and [5] the particles up to 2µm have a reduced influence over the intensity of wear while the particles between 2 and 10µm have a major influence on engine’s wear.

### 4 Results and interpretation

#### 4.1 Dynamic pressure drop

The dynamic pressure drop produced by the new and used air cleaners is presented in fig. 5.

Fig. 5 shows that the new air cleaners produce a pressure drop of 115Pa (N1), 116Pa (N2) and 96Pa (N3). The paper [11] presents a pressure drop value of 300÷400 Pa for the new air cleaners, in paper [13] the value is 100÷250 and in the paper [14] the value is 144.4 Pa. The values differ with the...
constructive-functional characteristics of the air cleaners.

The pressure drop produced by the used air cleaners was bigger than the one of the new ones. The values are different for used air cleaners – the maximum pressure drop was recorded for the filter with the highest mileage.

The maximum pressure drop for the used filters was 479 Pa and represents a rise by 383 Pa compared to the new air cleaner (N3). According to papers [8], [9] the filters must be replaced when the pressure drop rises by 2,500 Pa compared to pressure drop measured for new air cleaners. In the paper [5] was presented a filter used in real conditions for 30,000 km. The rise of pressure drop was 500 Pa for an air debit of 170 m³/h. In these conditions, the filter is about 20–25% of its lifetime.

As a first conclusion, the analysed used filters are in good condition and were prematurely replaced.

Even if the distance covered and the usage time of air cleaners U4, U5 and U15 were significant, the pressure drop showed only slight increases compared to the values measured for new air filters.

The pressure drop is not proportional with the usage period of the air cleaner. Similar conclusions are presented in paper [14].

This concludes that the main criterion for air filters replacement should be the gaso-dynamic resistance produced by them (considering the pressure drop) while the distance covered and usage period must be only secondary criteria.

### 4.2 The filtering efficiency

In the second part of the experiment, the filtering efficiency was determined for the three new air cleaners and two used ones. For the new air cleaners the initial efficiency was determined. The measured filtering efficiency of the new and used air cleaners after individually inserting a quantity of 20 g of dust is presented in fig. 5.

Fig. 5 shows the initial filtering efficiency values of the new filters N1-99.03%, N2-99.06% and N3-98.98%. In the papers [15], [16] and [17] is mentioned that initial efficiency depends on filtering material and usually has values between 95-99%. The tested air cleaners have good filtration efficiency. Both used filters have higher efficiency than the new ones. A similar conclusion is taken from paper [11].

Efficiency of used air cleaner U13 is significantly higher than the one of U1. It can be explained by the fact that U1 was very little used. In papers [1] and [5] it is mentioned that the efficiency continuously rises during lifetime and at the replacement moment, the efficiency can reach a filtering efficiency of 99.99%.

Taking into account the measured efficiency values of the used filters, they could still be used, making thus possible the rise of their efficiency. We may conclude that they were prematurely replaced.

### 4.3 The analyse of electron microscope images

Table 2 contains the number of identified particles for every sample of the analysed absolute filters.

<table>
<thead>
<tr>
<th>No.</th>
<th>Air cleaner</th>
<th>Number of particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N1</td>
<td>2043</td>
</tr>
<tr>
<td>2</td>
<td>N2</td>
<td>1830</td>
</tr>
<tr>
<td>3</td>
<td>N3</td>
<td>2028</td>
</tr>
<tr>
<td>4</td>
<td>U1</td>
<td>1422</td>
</tr>
<tr>
<td>5</td>
<td>U13</td>
<td>1269</td>
</tr>
</tbody>
</table>
From table 2 it can be observed that used air cleaners let go of a smaller amount of dust particles in comparison with the new ones. Filter U13 stopped the highest quantity of dust particles. This filter has the highest efficiency.

Figure 6 presents the percentage of particles with dimensions between 0-2µm, figure 7 presents the percentage of 2-5µm particles and fig.8 the percentage of particles with dimensions of 5-10µm.

From figure 6, it can be seen that the main amount of the particles passed through the air filter have dimension under 2µm. Those particles are not very dangerous for the kinematic couples of internal combustion engines.

Figure 7 shows that the particles with dimensions between 2÷5µm pass through the used air cleaners more rarely comparing to the new filters. These particles contribute mainly to engine wear according to [1] and [5]. The used filters offers higher protection to the engines.

Figure 8 shows that a small amount of dust particles with dimensions higher than 5µm pass through the air cleaner.

Figures 7 and 8 clearly illustrates that used filter U13 best protects the engine from dust particles with high potential wear.

5 Conclusion

The pressure drop measured for used air cleaners is higher than for new air cleaners.

The pressure drop of a used filter is not proportional with the covered distance of the car equipped with that air cleaner.

The main replacement criterion of an air cleaner must be the gaso-dynamic resistances produced by the air filter (the pressure drop).

Considering the obtained values of the pressure drop, a conclusion is that the air cleaners were prematurely replaced.

The tested new air cleaners have good filtering efficiency.

The used air cleaners have a higher efficiency than the new ones. The filtering efficiency rises as the filters are used.

Taking into account the obtained values for filtering efficiency for used air cleaners, we can conclude the air filters were prematurely replaced.

The used air cleaners reduce the quantity of particles that reach inside the engine and protects better than the new ones. Premature replacement of the air cleaner allow a higher amount of dust particles to reach inside the kinematic couples of the engine, thus intensifying engine's wear.

6. Acknowledgement

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References:


[9] Norman, K., Huff, S., West, B., Effect of intake air filter condition on vehicle fuel economy, Oak Ridge National Laboratory-

Managed by UT-battle for the Department of Energy, February 2009.


