Engine Air Intake Filters - consequences of premature replacement

Marius Toma

***Abstract*—** The life of an internal combustion engine is influenced by a multitude of parameters, engine's wear being one of the most important. The dust particles from the atmospheric air that pass through the air cleaners heavily influence their wear at the kinematic couples of internal combustion engines. 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, air cleaners with high filterring efficiency are used and also an increased importance must be given to maintenance activity. In this paper were tested original air cleaners manufacturer and aftermarket air cleaners. The following results are being presented: the pressure drop on air filters at the time of their replacement; the filtering efficiency of new and used filters; the size of dust particles that passed throught new and used air filters. This paper demonstrates that the replacement of air cleaners based on the distance travelled by the car or the usage time (in kilometres or years) without taking into account their real estate is uneconomical and disadvantageous due to technical state evolution of the engines.

***Keywords*—** air cleaners, efficiency, particle size, pressure drop, replacement period.

I. Introduction

THE life of an internal combustion engine is influenced by a multitude of parameters; engines' wear is one of the most important factors. In paper [1] is specified that 80% of the cases, the engines' lifetime is limited by the consequences of the wear. This happens when dust particles pass through air filter and reach inside the burning chamber and forward to the lubricant. Dust particles have different sizes, with sharp irregular shapes. Atmospheric air contains a multitude 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 air filter is influenced by many structural and functional parameters of the filter system as shown in [6].

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, [7];
- absolute filter—the filter downstream of the unit under test to retain the contaminant passed by the unit under test [8];
- differential pressure [7] (pressure drop [8])- difference in static pressure measured immediately upstream and downstream of the unit under test.

II. Literature References

In paper [9] 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 of air filters 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 [10].

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 gaso-dynamic resistances in the admission system, which at high levels cause a fall of the engine's power [11].

In paper [12] are presented usual values for the initial

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pressure drop of the air cleaners. For new air cleaners, the value is about 300÷400 Pa; these values are determined for a maximum consumed debit by the car's engine. Papers [13] and [14] measured the pressure drop of new air cleaners considering ISO5011 standards. For the cellulose fiber air cleaner, the pressure drop is 380 Pa at an air debit of 300 m^3/h [13].

In paper [14] the pressure drop for different materials of the air cleaners is about 100-250-350 Pa at an air debit of 155.4 m^3/h. Those values represent the pressure drop strictly related to the air cleaners, without considering air cleaner's case. Papers [9] and [10] suggest that the air cleaners must be replaced when the pressure drop rises by 2,500 Pa, compared to the initial value measured on the new filter.

During time, an air cleaner efficiency increases. 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 cellulosic 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 10.8 g/m^2 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], [16], [17], [18].

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. Particles with dimensions of 4-5 µm produce a significant wear, while the particles up to 2 µm 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 1 µm. Paper [5] presents the fact that particles smaller than 10 µm, namely 0-5 µm and 5-10 µm produce four times higher wear than the particles with dimensions between 10-20 µm.

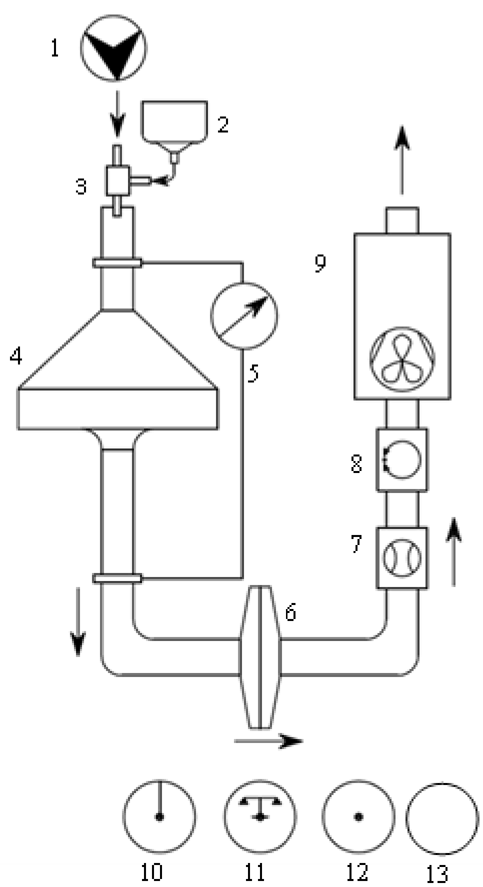
III. Experiment

The study consists of measuring the filtering efficiency for new and used air cleaners. For each type of these air cleaners, measurement of the pressure drop will be made in laboratory conditions. In the same time, the size of the dust particles that pass through the air cleaners will be analized. 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.



1. compressor; 2. dust tank; 3. dust injector; 4. the case of air cleaner; 5. manometer; 6. absolute filter; 7. air debit measuring device; 8. the device of setting the air flow; 9. exhauster; 10. thermometer; 11. weighing machine; 12. barometer; 13 hygrometer.

Fig.1 Schematic test setup

The tested air cleaners are for K7J şi 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 [19], [20].

The tested air cleaners will be symbolized as follows:

- depending on the air cleaner's manufacturer: type "A", type" B ", type " C ";
- depending on their state: new „N" or used„U".

During the experiments, 10 filters were tested: 6 were new (2 type "A", 3 type" B ", 1 type "C") and 4 were used (2 type "A", 2 type" B). The three types of filters are used in service stations for preventive maintenance activity. The „A" type air filters are equipping new cars, (Original Equipment Manufacturer). The „B" type air filters are approved by the car manufacturer and used in service stations for preventive maintenance activity. The „C" type are aftermarket air filters with a lower cost compared to „A" and "B" types.

The used filters are from cars in usage and have been collected from service stations when cars arrived for planned maintenance activity. 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, for used air cleaners, the real data from exploitation and the environment where the cars were used. These air filters were on Renault K7M engine. The data were collected from the car owner (the service station's customer).

Table 1 Exploitation data for the used air cleaners

No	Air cleaner	Exploitation conditions		
		Covered distance [km]	Length of time [months]	Regional movement
1	UA1	~15000	12	combined ***
2	UA2	~15000	12	urban**
3	UB1	~15000	12	combined ***
4	UB2	<15000	-	extraurban**

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

UB2 air 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 UA1, UA2 and UB2 filters is common to the most of the collected filters.

The study was conducted in several stages:

- measuring the dynamic pressure drop before inserting dust inside the air cleaners;
- measuring the filtering efficiency;
- measuring the dynamic pressure drop after inserting dust inside the air cleaners;
- image analyze of samples from the absolute filters, images obtained by the electron microscope.

MEASURING THE PRESSURE DROP

The pressure drop produced by each air filter was measured in two stages: after mounting the air filter on the stand, before starting inserting the dust and will refer to it as initial pressure drop and the second stage, after inserting the dust into the filters and will be refered further as final pressure drop.

The tests were made at the highest air debit of 208 m^3/h consumed by the Renault K7M engines [21].

MEASURING THE FILTERING EFFICIENCY

The efficiency of the air filters was determined after inserting 20 g of dust inside the air cleaners. This represents the initial filtering efficiency for the new filters according to [1].

The air debit through the filters was 208 m^3/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 40 µm.

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 40-100 µm.

The absolute filter has a progressive structure composed of two parts and four layers of nonwoven tissues. First part contains three layers of fibers with progressive structure and represents the absolute filter and the second part has one layer. Layers three and four are of the same material (Fig.2). The fourth layer was used to check if the particles are fully retained by the first structure.

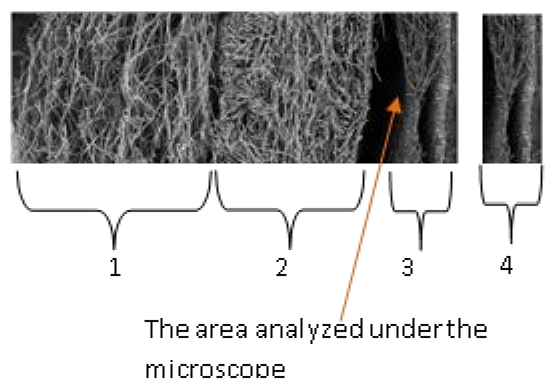


Fig. 2 The aspect of absolute filter - section

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 [7].

Before use, the dust was heated in a vessel up to temperatures over 100°C to eliminate the humidity as standard recommend [7]. Thus, the humidity was eliminated and then the air filters were weighed.

IMAGE ANALYSE OF THE SAMPLES FROM THE ABSOLUTE FILTERS

For each analized filter which was determined the filtering efficiency, an absolute filter similar to the one from Fig. 2 was used.

From every absolute filter, samples of filtering material were taken from the central zone.

By taking and analyzing 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.

The electron microscope analyses were made by a qualified person. The obtained images have scales of 200, 100, 50 and 10μm. Only images with 100μm scale were analyzed (fig.3).

The images obtained by an electron microscope were processed using ImageJ software, applying "Analyse Particles" function [22].

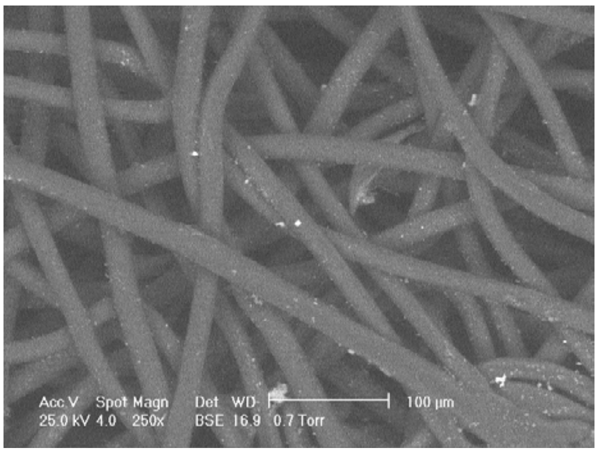


Fig. 3 A sample of absolute filter

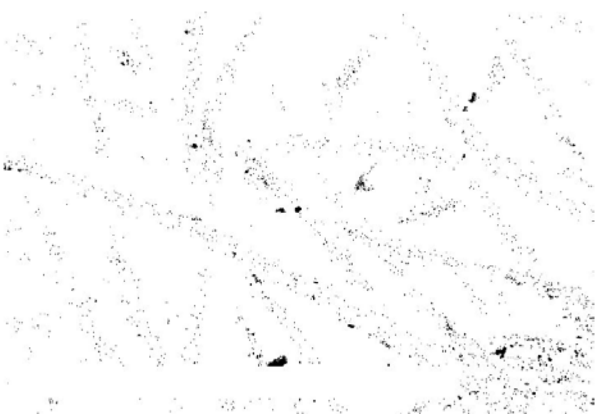


Fig. 4 Dust particles identified by ImageJ software

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 analyze.

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: 0-2 μm; 2-5 μm and 5-10 μm.

According to the papers [1] and [5] the particles up to 2μm have a reduced influence over the intensity of wear on the kinematic couples of internal combustion engines, while the particles between 2 and 10μm have a major influence on engine's wear.

IV. Results and interpretation

The pressure drop

The initial pressure drop produced by the new and used air cleaners is presented in fig. 5 and the final pressure drop in fig. 6.

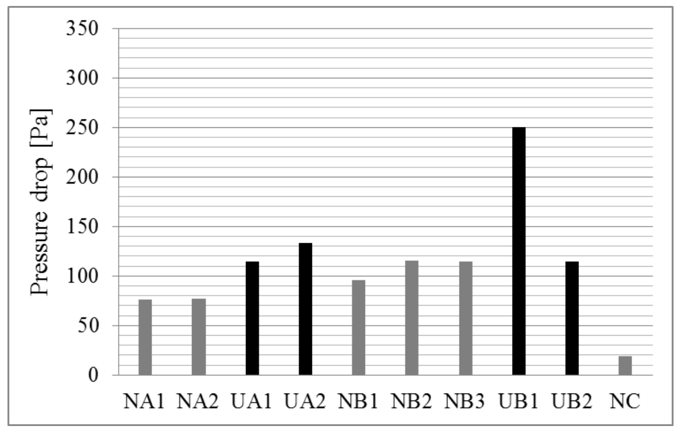


Fig. 5 Initial pressure drop

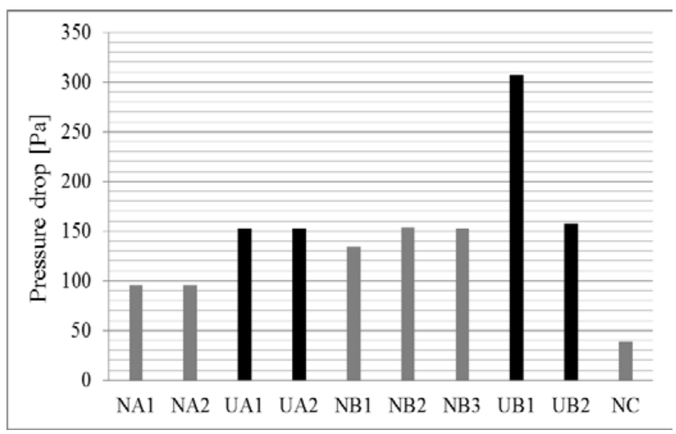


Fig. 6 Final pressure drop

Fig.5 shows that the new air cleaners produced a pressure drop of NA-77 Pa, NB:96-116 Pa and NC-20 Pa.

Paper [12] presents a pressure drop value of 300÷400 Pa for the new air cleaners, in paper [14] the value is 100÷250 Pa and in the paper [15] the value is 144.4 Pa, depending on the constructive-functional characteristics of the air cleaners.

The pressure drop produced by NC air cleaner is significantly lower than the pressure drop produced by A and B filters and the one mentioned in the relevant literature. This may be due to the structure (constructive particularities) of the filtering material.

The initial pressure drop produced by both types of used air cleaner is higher than the pressure drop produced by the new ones, considering that the used filters have already a quantity of dust retained in its fibers.

The final pressure drop produced by NA and NC filters increased by 20 Pa and NB filters by 40 Pa. The final pressure drop produced by used filters increased by values between 20 and 60 Pa.

The increase of pressure drop after inserting 20 g of dust into new and used filters is very low. For new filters, the experiment shows that they can store large quantities of dust, like 100 g, without significant increases of the gaso-dynamic resistances. For used filters, the reduced pressure drop increase shows that they collected small amounts of dust during explotation.

In ordinary exploitation conditions (travelling, environment), the amount of dust stored in a car's air filter is 100 g at 480,000 km, with an increase of the restriction of maximum 2,500 Pa according to [15], [16], [12] . For a vehicle, depending on the constructive-functional characteristics of the air cleaners, it can store between 100-250 g of dust [12]. Paper [1] estimates that under ordinary exploitation conditions, filters collect up to 2 g of dust at 1,600 km mileage.

According to papers [9], [10] 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 m^3/h. In these conditions, the filter is about 20-25% of its lifetime.

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

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.

THE FILTERING EFFICIENCY

In the second part of the experiment, the filtering efficiency was determined. For the new filters, the initial efficiency was determined, according to [7]. The filtering efficiency after inserting 20 g of dust into new and used filters is presented in Fig 7.

Fig.7 shows that the initial efficiency of new air filters is NA1- 99.19%; NA2-99.21%; NB1-98.98%; NB2-99.04%, NB3-99.06% and NC-98.58%. In the papers [16], [17] and [18] is mentioned that initial efficiency depends on the filtering material and usually has values between 95-99%. The tested air cleaners have good filtration efficiency.

The used filters, of both types, have higher efficiency than the new ones. A similar conclusion is taken from paper [12].

The air cleaners type A have better filtering efficiency than type B, both new and used. Therefore the original air cleaners have a higher filtering efficiency. The air cleaners type C since it has the lowest filtering efficiency, it offers the lowest protection for the engine.

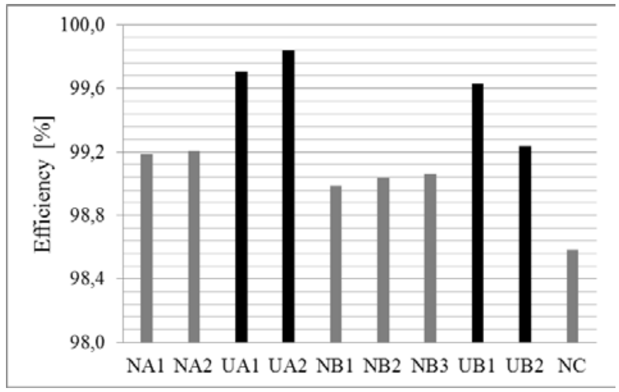


Fig. 7. The filtering efficiency

Efficiency of used air cleaner UB1 is significantly higher than the one of U2. It can be explained by the fact that U2 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.

THE ANALYSE OF ELECTRON MICROSCOPE IMAGES

Fig. 8, 9 and 10 presents the percentage of particles contained in the analyzed samples of the absolute filters. Fig. 8 presents the percentage of particleswith dimensions between 0÷2 µm, fig. 9 with dimensions between 2÷5 µm and figure 10 dimensions between 5÷10 µm.

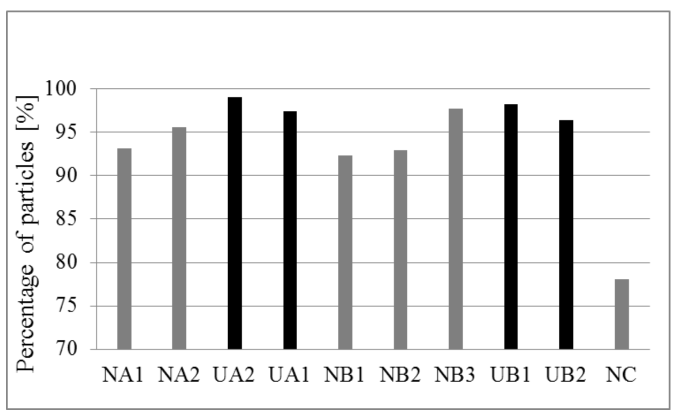


Fig. 8 The percentage of particles with dimensions of 0-2 µm

From fig. 8, it can be seen that the main amount of the particles passed through the air filter have dimension under 2 µm. Those particles are not very dangerous for the kinematic couples of internal combustion engines.

Fig. 9 shows that the particles with dimensions between 2÷5 µm pass through the used air cleaners more rarely comparing to the new filters. These particles contribute mainly to engine's wear according to [1] and [5]. The used filters, type A and B offers 2-3 times higher protection than new filters of the same type.

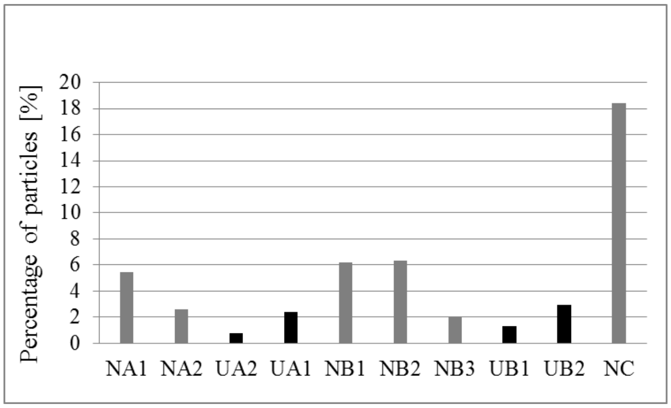


Fig. 9 The percentage of particles with dimensions of 2-5 μm

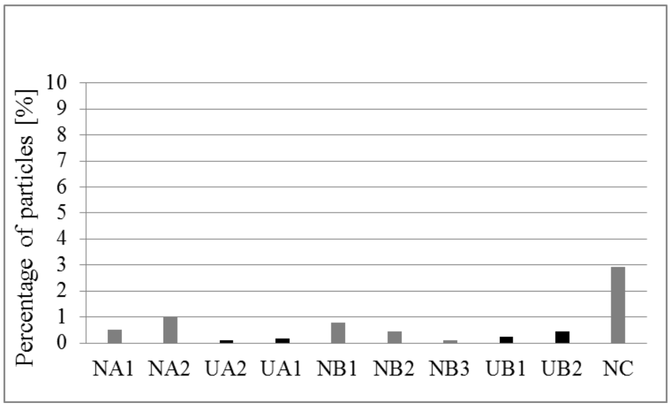


Fig. 10 The percentage of particles with dimensions of 5-10μm

Fig. 9 and 10 shows that NC air cleaner allow the particles with high wear potential for the engine to pass in a higher proportion than NA and NB filters. Although it has a good filtration efficiency, NC filters provide a significantly less protection compared to NA and NB filters. From used filters, UB2 has the highest wear potential since allowed the highest quantity of particles to pass. This is expained by the fact that UB2 was less used than the others before being replaced.The used filters, both types better protect the engine from dust particles with high potential wear,compared to the new filters.

V. Conclusion

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

The increase of pressure drop after inserting 20 g of dust into new and used air filters is very low.

Replacement air filters depending on the distance traveled by car or expoitation time is inadequate.

To protect internal combustion engines against abrasive wear, the main criterion for replacement the air filters should be the values of the gaso-dynamic resistances (appreciated by the pressure drop).

Considering the obtained values of the pressure drop, a conclusion is that the tested used 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.

The number of particles that reach inside internal combustion engines decrease while using the filter. The used filters, of both types, better protects the engine than new filters against dust particles with high wear potential.

The „A" type air filters ensure greater protection than aftermarket air filters.

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

Premature replacement of the air cleaner results in the intensification of the wear at the kinematic couples of the engine.

Acknowledgment

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